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(INSTITUTED 1852.)

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No. 797.

NOTES ON EARLY PRACTICE IN BRIDGE BUILDING.

By George E. Gray, Hon. M. Am. Soc. C. E.

Presented November 18th, 1896.

WITH DISCUSSION.

In reviewing the paper entitled "What Is the Life of an Iron Railroad Bridge?"* by J. E. Greiner, M. Am. Soc. C. E., and the discussion on it, the author was particularly interested in the remarks of T. C. Clarke, M. Am. Soc. C. E., and Walter Katté, M. Am. Soc. C. E., referring to certain bridges on the New York Central and Hudson River Railroad. The conclusions arrived at by these members on this question are, in the author's opinion, generally correct. These conclusions are that the practice of placing the diagonals closer than is now customary led to diffusing the strains over a large number of points rather than concentrating them on a few, which is one of the reasons the bridges stood so well. Mr. Katté was of the opinion that solidly riveted lattice girders, up to spans not exceeding 200 ft., give unquestionably the best service for such constant and heavy traffic as that on the New York Central system.

* See *Transactions*, Vol. xxxiv, p. 294.

It was contemplated in the original design for the bridges referred to, to connect all of the parts by riveting, thus diffusing the strains throughout the whole structure. The advantage of this system was soon clearly illustrated at a bridge of this type just erected over the Erie Canal near Newark, N. Y. A fast express passenger train was bound westward, and as it approached within a few feet of this bridge the axle of the forward driving wheels, outside connections, broke off close to the right-hand wheel. This left the wheel free, and, being propelled with great velocity forward, it left the rail, striking in its course the second outside right-hand post, from the easterly end of the bridge, cutting the post off entirely, together with several tension bars. In addition, the third and fourth posts were nearly severed and several tension bars more or less cut away, but the rigid connections of the structure carried the train over safely, and, in fact, there was no delay in passing all other trains while repairing the damage. It is gratifying to the author to hear, after so many years, such testimony in recognition of the labor and efforts of himself and his able assistant, the late Col. Howard Carroll.

The bridges referred to were designed and constructed before 1864 and 1865. It may be of some interest, historically, to engineers and others to know, what the author believes to be true, that the New York Central Railroad Company was the first to build an all wrought-iron bridge of any considerable span for railroad use in the United States. Several bridges, cast and wrought iron combined, had been constructed on the Whipple and other designs, but the failure of one of them on the New York and Erie Railroad, through the ignorance of track men, caused railroad officials to look with distrust on any iron bridge.

The process that led up to the adoption of iron for bridges in the United States was slow. The author, as chief engineer of the New York Central Railroad Company, was directed to examine carefully into the subject of iron bridges and report to its Board of Directors. The high price of iron and the general lack of knowledge of its use for such purposes in the United States made it difficult to get a reasonable consideration of the subject by those high in authority. In working out the plans and strain sheets a serious question arose as to how much a given section would bear under compression without bending. Upon this question the highest authority then accessible

was silent, and the author had to work it out by erecting the proper testing machinery for that purpose at the New York Central shops at Albany, N. Y. Finally, when authority was obtained and plans and estimates prepared, the directors and officials were skeptical. To convince the skeptics, a single-track bridge of 30-ft. span, proportioned to 1 ton per lineal foot, was built at Schenectady, solely for tests, and to be so used until broken.

A 28 to 30-ton locomotive, the heaviest then on the road, was run over this bridge at high speed without any defects appearing. Thereafter the bridge was loaded by dead weight, evenly distributed, to over 4 tons per lineal foot, when the bridge failed from a defective tension bar. Up to this period the rule had been to proportion all bridges to a load of 1 ton per lineal foot. Soon after the rule was changed to a proportion of 2 tons per lineal foot, this being in view of the demands of increasing traffic and the constant tendency to enlarge the capacity of locomotives and rolling stock generally.

The question of corrosion entered seriously into the author's calculations originally. Skeptics made telling arguments as to the unreliability of iron on that account, therefore extra precautions were taken to protect each part of the iron promptly on delivery. Long after, so anxious had the author become on this subject, and fearing neglect to keep the bridges well protected from so insidious an enemy, he wrote from California to his direct successor, Mr. Charles Hilton, and again to Mr. Charles H. Fisher, his successor, both among his former assistants on that road, calling their attention to this subject and urging watchfulness and care. Mr. Fisher replied, that, mindful of the danger, he had called the attention of his superiors to this subject; that they had expressed no concern, were apparently indifferent, and, furthermore, said that the danger, if any, was so remote there was no need of apprehension. An inspection of the bridges referred to should bear witness of any damage by corrosion after a period of 35 years or more.

Can the engineer be held responsible when his principals are so indifferent to the inroads of such an enemy as corrosion, in fact, the only enemy of any account the engineer has to fear?

The author is wedded to rigid connections and would not limit spans to 200 ft., as proposed by Mr. Katté, except on economical grounds, such as rapid erection, or the continuous running of trains

during erection. Riveted connections largely avoid vibration, the great demoralizer of all iron and steel bridges. It is his firm belief that had a bridge with pin connections been in the place of the present bridge at Newark, erected over 32 years ago, the whole train, with its precious load of passengers, would have been plunged into the Erie Canal below.

To the engineer of this date, with all the accumulated knowledge and experience of the past 35 years, with perfection of machinery and material and the developed science of bridge building, the foregoing remarks may seem not worth commenting upon; but he should feel thankful that those who preceded him had made his road easier and that he is not hampered, as they were, by lack of experience, a very meager bridge literature and prejudiced opposition.

DISCUSSION.

GEORGE H. THOMSON, M. Am. Soc. C. E.—The author's early advocacy of iron bridges for the New York Central Railroad and his persistent efforts with the railroad officials, resulting in the adoption of wrought-iron structures, are not generally recognized as they should be. As chief engineer of that line, he had for his bridge assistant Col. Howard Carroll, whose first work was the bridge over the Mohawk River at Schenectady, still in service. Mr. Thomson.

Col. Carroll designed in riveted lattice. In the grouping of rivets for specific stress modern designs do not excel, and often do not equal, the nicety and precision shown in some of his early bridges. For tension, he used flats or plates only; for compression, he used angles latticed, or angles and plates. His top chords were of plates and angles, and continuous throughout the entire length; his floors were made of track stringers and floor beams (plate girders), except in double-track bridges, where the floor beams were of lattice trusses. His lateral systems were of flats. In one of his bridges still in service rivets of $\frac{3}{4}$, $\frac{7}{8}$, 1, $1\frac{1}{8}$ and $1\frac{1}{4}$ ins. diameter are found. He used panel-point plates in his truss connections. The first specification for riveted bridge work known to the speaker as made by Carroll is dated 1857; it is the prototype of current specifications for riveted work.

Mr. Charles Hilton, a pupil of Col. Carroll, took the latter's place on the New York Central and subsequently became its chief engineer. He followed Col. Carroll in design, with some modifications. In lattice bridges of the pony type, he riveted the floor beams to the verticals with rivet section in excess. In spans of 150 ft. he used the multiple system where a web tension set at 45° covers four panels of the truss as shown in Fig. 1. His top chords were like Col. Carroll's, continuous throughout the entire length; his floors were sometimes made of 9-in. I-beams, spaced 20 ins. centers, and hung from the bottom chords by tension rivets. These I-beams supported longitudinal timber stringers upon which the rails rested. His web compression members were sometimes made of rolled beams and channels.

In 1864 Mr. Hilton changed his designs. He no longer used the Pratt system, but the diagonal system. He made his subpanels about 10 ft., as shown in Fig. 2. He used stiff lateral systems everywhere. Twenty-one years ago the speaker as a draftsman drew pin-connected bridges for Mr. Hilton in which all the laterals were stiff and riveted. His tension members were of angles, or such sections as had a considerable moment of inertia, so that if any member should be called upon temporarily to do duty in compression or as a beam, it was, in a measure, available therefor.

Mr. Thomson.

Mr. Hilton's first diagonal lattice was the bridge over the Erie Canal near Canastota. The bridge is illustrated in the "Manual for Railroad Engineers," by Professor G. L. Vose, but the attachment of the floor beams to the chords was by a diaphragm distributing to both webs of chords, and not as shown in the book mentioned.

Mr. Hilton was not inclined to eccentric connections, however, and he abandoned panel-point plates after 1862. He always had in mind elastic relations, especially in truss connections, and therefore the connection of a thin angle to a thick plate is not found in his designs. Fig. 3 shows one of his diagonal-system bridges. The horizontal member –*y*– takes both tension and compression; this member is left out in European bridges of this type. He computed trusses from engine

FIG. 1. CARROLL THROUGH LATTICE

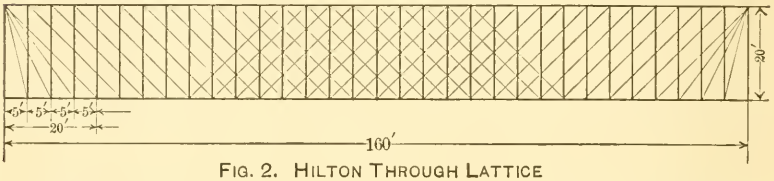


FIG. 2. HILTON THROUGH LATTICE

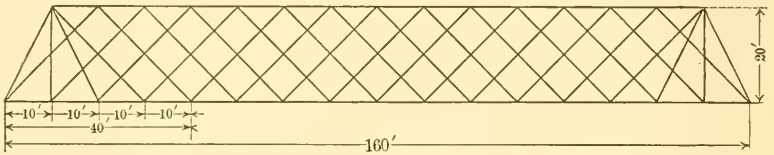
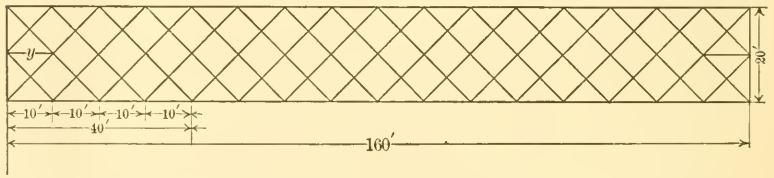


FIG. 3. HILTON LATTICE



wheels in the year 1862, and, prior to 1878, made specifications for wheel loads such as are now current.

A. S. C. Würtele, M. Am. Soc. C. E., began in 1868 to design lattice bridges following closely Mr. Hilton's practice. In 1869, S. J. Fields, M. Am. Soc. C. E., a pupil of Mr. Hilton, designed lattice bridges, following the same practice with improvements in details of chords, etc. Charles McDonald, M. Am. Soc. C. E., about 1875, also designed lattice bridges with improvements in details. In 1876, John F. Alden, M. Am. Soc. C. E., a pupil of Hilton, further improved details.

As early as 1873, the speaker talked over the matter of short versus long panels with Mr. Hilton, and in 1885 he began to use long panels,

up to 32 ft. length, in lattice bridges. After twenty years' acquaintance with multiple systems, and consequent short panels, he is in favor of the long panels provided there is one intersection of web members, as in Fig. 4. They are cheaper, and the valid conclusions of those that favor diffusion of stress and dispersion of members hold good for them. The objection to them as regards inadequate diffusion of stress is not borne out by gauging; there is less structural motion in the long than in the short-panel lattice bridges of the same weight. Mr. Thomson.

If the invasion of rivets is observed in the details of pin-connected bridges for twenty-five years past, together with continuous top chords, riveted floor beams and stringers with their rigid connections, plate girders, etc., the influence, pervasive and permanent, of Messrs. Carroll and Hilton will be detected. A modern bridge cannot be found void of the evidences of their thought and work. The ideas of engineers change. Twenty-three years ago but one shop in the

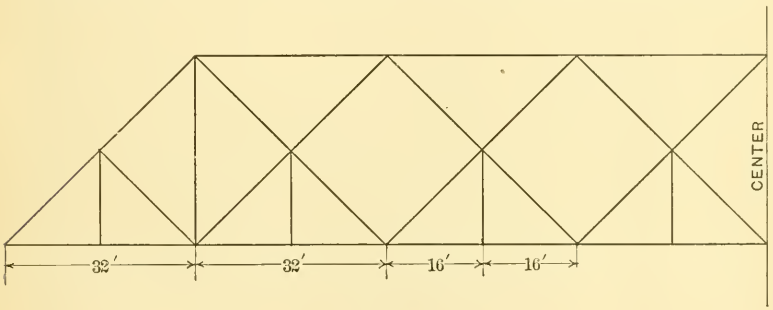


FIG. 4.

United States built lattice bridges, and ten years ago the speaker was severely criticised for advocating as economical plate girders of 100-ft. span for certain well-defined situations. Long plates are now common enough, and in his own practice he has erected about 100 spans of long plates up to 123½-ft. span since 1885.

The acceptance of rivet work has become so thoroughly established, and the principles governing the design of rivet construction as set forth and exemplified in the practice of Messrs. Carroll and Hilton are so generally followed, that the old battle of pins versus rivets seems an idle pastime. At the present date there are able engineers who do not hesitate to design an unprecedented long span suspension bridge with stiffening trusses of the lattice type, and design a drawbridge of the 1864 Hilton type.

The pin-connected bridge of modern design, barring its main connections of forged eye-bars, its non-intersection of web members, and its indirect lateral attachments, embodies the principal features of the

Mr. Thomson. lattice bridge. The future will further develop and possibly further merge the two systems.

There is much chance for advance in the design of bridges of the lattice type, but before much success can be obtained in that direction, there needs to be change in cerebration; more freedom and less "daddyism." The speaker would not undertake to define freedom, as a comprehensive consideration of all the points involved is far beyond his ability and research. However, he would attempt a definition of "daddyism," which can be considered as provisional only, as follows: "Daddyism" is that incoherent, indeterminate, indefinite and almost indescribable manifestation of consciousness as expressed through the personality, which leads the mind to assume that things as they exist, and relations between things as they obtain, are the same as one's concepts of things, and the relations between them ; the result of this assumption, this mode of thinking, is error ; its product is progress of the negative order, that is to say, retarded progress.

By structural motion, referred to in connection with the bridges built by Mr. Hilton, the speaker meant the motion induced in bridges by the imposition and passage of the rolling load. "Motion" *per se* cannot be defined, and a definition of structural motion would involve an acceptable definition of that which in its nature is indefinable. However, the time may come when a provisional definition of motion may be established ; until then a theory of structural motion cannot well be set forth. Looking over the old Carroll bridges it was found (by computation and gauging) that many members were stressed up to 25 000 lbs. per square inch without any visible evidence of elongation, loose rivets, etc. The observation of the speaker, confirmed by the study of structural motion, is that in railroad bridges free from undue motion a stress of from 20 000 to 25 000 lbs. per square inch need not always cause alarm, but much motion under low stresses may be of sufficient importance to suggest to the engineer an inquiry as to the validity of his grounds for the assumption of potential strength resident in his material.

An engineer handles forces primarily, and material secondarily. He is supposed to know the quantity of force stored up in his material, and also how long it can be kept there controlled and subject to the uses he intends, for "matter is force in bondage."

As to the magnitude of force immediately present in a piece of steel, for instance, its "properties" afford a criterion ; as to the conservation of this force, its availability for repeated and long-continued service, and therefore the measure of the assurance and dependence thereon, "quality" offers a criterion. The speaker had not seen, so far, a specification for bridge material that indicated discrimination as to the difference between "property" and "quality."

Mr. Blakeley.

GEORGE H. BLAKELEY, M. Am. Soc. C. E.—There are numerous recorded instances where riveted lattice railway bridges have withstood, without collapsing, the blows and shocks caused by collisions and derailed cars, while there are few records of pin-connected railway bridges standing up under such shocks. The number of riveted lattice railway bridges in use in this country is unquestionably less than the number of pin-connectedbr idges; consequently, it is reasonable to conclude that fewer accidents, in the aggregate, occur upon riveted lattice railway bridges than upon pin-connected. Notwithstanding this, the reported instances where the riveted type of bridge has successfully withstood severe accidents are far more numerous than for the pin-connected type. It does not necessarily follow that the pin-connected type is totally unfitted to withstand such accidents. The speaker is aware of several instances where pin-connected railway bridges have withstood tremendous shock and injury without collapsing, yet such instances were never reported or published in the technical press. The advocates of the riveted type of bridge are more earnest in their advocacy than those who have faith in the pin-connected type.

Charles W. Buchholz, M. Am. Soc. C. E., kindly furnished the speaker with a description of an accident to a double-track pin-connected bridge on the Erie Railroad. The character of the accident and the method employed by him in temporarily repairing the damage is of such interest as to warrant being given in detail.

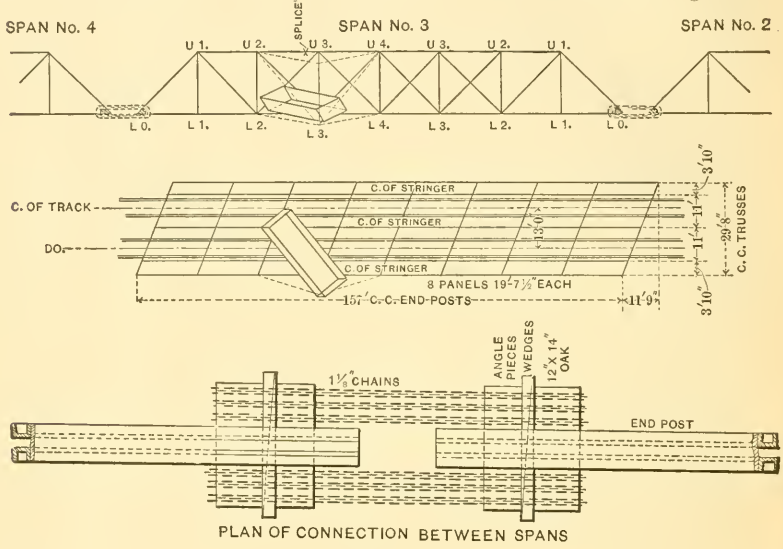
Bridge No. 9, Delaware Division, was built in the fall of 1879. In February, 1890, a coal car on an east-bound train was derailed about 800 ft. west of the bridge, and running on the ties until it reached span No. 3 the forward trucks were slewed, and, mounting the guard ribbon at about the west end of span, the car crashed into the vertical post, L3, U3, as indicated in Fig. 5. The car broke this post off about 3 ft. above the center of the bottom chord pin, bending the upper portion of the post outward, and remained stationary with about one-third of the body of the car projecting outside of the truss, directly above the pin and partly supported by the lower end of the broken post, the forward trucks being shoved backward to near the center of the car. The car was a 50 000-lb. capacity hopper-bottom gondola loaded, the total weight being about 88 000 lbs.

The first thing done after the arrival of the wrecking crews was to hew out large triangular oak blocks to fit in the angle formed by the inclined end post and the top of the bottom chord bars close to the pedestal shoes. These blocks were placed on each end of the damaged truss, and on each of the adjoining spans. Twelve by fourteen-in. oak blocks were then placed close to the triangular blocks, and heavy wrecking chains with $1\frac{1}{8}$-in. links were wrapped around the ends of each of the adjoining 12 x 14-in. oak blocks. Wedges were then placed between

Mr. Blakeley.

the triangular and 12 x 14-in. blocks and driven home, thus bringing a good tension on the chains, and forming a connection to each span at each end of the damaged truss, so that it would be necessary either to break six ply 1⅛-in. chain, or drag one or both of the fixed spans off the pier or abutment, before the span that was damaged could be totally wrecked.

While some of the wrecking crews were connecting up the trusses, others were busy blocking and clamping the main bars L4, U3, L3, U2, and forming them into struts. Others were at work cutting cribbing pieces to distribute the weight over the lower chord, framing around the lower portion of the broken post, and making a bearing for a temporary post made of two pieces 8 x 18 ins. bolted together



PLAN OF CONNECTION BETWEEN SPANS

Fig. 5.

and fitting close to a crosshead timber on the under side of the top chord. While this was being done a gang of men was shoveling the coal out of the wrecked car. When the car was empty a wrecking car was run on the west-bound track by hand power, and the body of the coal car taken off, and afterward each of the two pair of trucks. When this had been done, the temporary post and cribbing that had been prepared were placed in position and wedged to a good bearing.

Traffic was then resumed on the west-bound track, and temporary bents, previously framed, were then placed in position under panel points L1, L2, L3 and L4 of the south truss for greater safety and in order to be prepared to change the temporary post when neces-

sary, and traffic was resumed on the east-bound track. Panel points L3, U3 were each about 3 ins. below camber during the time that wrecking was progressing, but were brought back to position, after temporary bents were placed and correct centers obtained, by adjusting the wedges between cribbing and temporary post, and the wedges between the temporary bents and bridges. Mr. Blakeley.

The top chord splice was located 18 ins. from the center of the pin, and while the rivets in side splices sheared off at this point, those in the cover-plate splice held.

This instance is not cited as an argument for the superiority of the pin-connected type of railway bridges, nor is it cited to disparage in any way the merits of the riveted type. The riveted type of bridge has many commendable features, and it is being more largely used for railroad bridges than heretofore.

James Owen, M. Am. Soc. C. E.—On one occasion a derailed coal car struck the cast-iron pocket under an end post of a pin-connected bridge on the Delaware, Lackawanna and Western Railroad. The bridge had an ordinary portal. The pocket was carried away, leaving the post without any support, but the bridge remained standing, although the first cross-girder sank $1\frac{1}{2}$ to 2 ft. Mr. Owen.

In designing highway bridges, the speaker long ago adopted a 100-ft. span as the limit of pin-connected work. Spans up to 35 or 40 ft. he now builds of rolled beams, and from that up to 70 or 80 ft. of plate girders. Most of his highway work is now made with beams and girders, with arches turned between them, and a concrete floor to carry the pavement. The dead load is largely increased in this manner, running up to about 300 lbs. per square foot, but the factor of safety can be reduced.

There are certain elements to be considered in highway bridge practice which need not be taken into account in designing railway structures. One of these is the vibration produced by fast traveling vehicles and light trotting wagons, which will cause more tremor in a bridge than will a heavy locomotive. In early pin-connected bridges, the speaker was continually troubled by lateral tie bars hitting the posts, and he was forced to bind the bars and posts together to prevent their rattling. This seemed essentially improper from an engineering point of view, and his later work has been built without any bars in it, all parts being stiff work of sufficient size to take up the vibration.

A rather curious loading for a plate girder bridge noticed by the speaker was caused by a contractor's poor judgment. A sewer had been built beside the structure, and the contractor had piled the earth on it until the load amounted to about 950 lbs. per square foot. The speaker looked underneath the span with considerable anxiety, but found no deflection.

Mr. Hardy. GEORGE R. HARDY, M. Am. Soc. C. E.—In the matter of vibration of tension members against posts, reference may be made to the fact that certain precautions had to be taken at the lower bridge at Albany, N. Y., to prevent the wearing of these members in this way. This bridge is a structure designed by the late Charles Hilton, and is pin-connected, a rather strange fact, in view of his later work being chiefly riveted. A few years later he designed the upper Albany bridge, which was a riveted structure entirely. Perhaps ten years later, the speaker asked Mr. Hilton's opinion as to the relative merits of the two systems of bridging, then a subject of considerable discussion, and he expressed himself very much in favor of the use of pin-and-link work under certain conditions. It would be interesting to learn of any good objection to such work in long deck spans where there is no opportunity for a catastrophe to be occasioned by the train service.

CORRESPONDENCE.

Mr. Thomson. T. KENNARD THOMSON, M. Am. Soc. C. E.—If all engineers had paid as much attention to painting as the author, there would be some bridges still standing which are now in the scrap heap. The writer has rebuilt bridges, which had stood rough and heavy traffic for twenty-five years, in which the iron was as good as new. In these cases they had been thoroughly cleaned and painted with pure red lead, and the iron had never been exposed. On the other hand he has condemned and rebuilt bridges which had been in use only a few years, but were dangerously pitted, although they had apparently been kept painted. The rusting had started and continued under the paint until scale $\frac{1}{8}$ in. thick could be picked off with the fingers from channels which were originally only $\frac{1}{4}$ in. thick.

Steel, after once rusting through the outer skin, seems to keep on rusting even if well painted, yet many bridge companies will not take steps to prevent this rusting starting, and some do not even see the use of removing the mud. Consequently there are many structures which have not been up a year in a worse condition than others after twenty to thirty years.

The writer once had charge for a railroad of replacing at the same time two old viaducts several miles apart. On arriving at one of these one day he found the foreman, supposed to be an exceptionally bright man, had knocked out the struts and eye-bars of some 30-ft. Fink trusses, leaving just one 15-in. I-beam 30 ft. long under each rail, and at least one-half the section had been cut from the center of these beams for the strut connection, etc. The ties had been left on 15 ft. of the 30-ft. span. The foreman argued that as these 15-in. beams

had carried the load unsupported for 15 ft., therefore it was just the same thing to have a 30-ft. beam span if it were loaded for only 15 ft. This was on a 6° curve, 2% grade, with heavy coal traffic; as it seemed impossible to convince him of his error, the trains were flagged and held until the viaduct was made safe. Had the writer happened to be at the other viaduct at the time, and he had more than enough to do at each place, the train and his reputation would have gone down. The viaduct was over 100 ft. high. Mr. Thomson.

E. B. Cushing, M. Am. Soc. C. E.—The author's belief that disastrous results would have followed had a pin-connected span been subjected to the same severe test as the lattice truss mentioned in the paper is no doubt correct. There are a number of cases on record where bridges of the former type have failed owing to the destruction of a post by being struck by a part of the load on an open car becoming displaced and projecting beyond the clearance line, or by derailed cars. While it is possible to reduce greatly the danger of accidents to pin-connected bridges by proper re-railing devices, the introduction of short struts to strengthen end-posts against shock, and other comparatively inexpensive means, it is hardly practicable to build a pin-connected span that would resist such a severe test as the one mentioned in the paper. The diffusion of strains over a number of points and the prevention of vibration are features that strongly recommend the rigid type of bridge. The ordinary bridge foreman, while perhaps duly diligent in keeping in repair the wooden trestles on his division, seems to regard the iron bridges as being able to take care of themselves, and unless constant watchfulness is exercised will permit these structures to get out of adjustment. The constant working of the members of a badly adjusted span under traffic sometimes causes injuries. This is especially true in the short pin-connected spans where the dead weight is so much less in proportion to the live load, and there is little to check vibration. The writer has never seen a bridge member fail under direct stress, but has seen instances where it became necessary to replace a web member, owing to injury through bad adjustment. In riveted spans this element is reduced to a minimum. Even the partial application of this type of construction, as, for instance, the riveting of stringers to floor beams, instead of the old method of placing them on the floor beams and the use of stiff braces instead of rods in trestle towers, has resulted in much more satisfactory practice. Mr. Cushing.

Another point that recommends the use of girders and of lattice trusses for openings of reasonable length is the facility and rapidity with which they can be erected. Recently the Cleveland, Akron and Columbus Railway, in replacing a wooden Howe truss span, decided to use a 91-ft. plate girder. This girder was designed to carry two engines, each weighing 120 tons, followed by a train weighing 3 500

Mr. Cushing. lbs. per lineal foot. In order to cause no delay to traffic, while dispensing with the use of any falsework, the girders were riveted up complete on the cars. They were then swung on gallows frames and lowered into place. The entire time consumed, from the time cars were placed until trains were passed on the new tracks, was less than six hours. Such work would be impossible with a pin-connected span.

Riveted lattice spans require, generally, more metal than the pin-connected type, and the proportion increases with the length of span, so that the point at which it is necessary to adopt the latter type depends upon the extent to which owners of properties are willing to

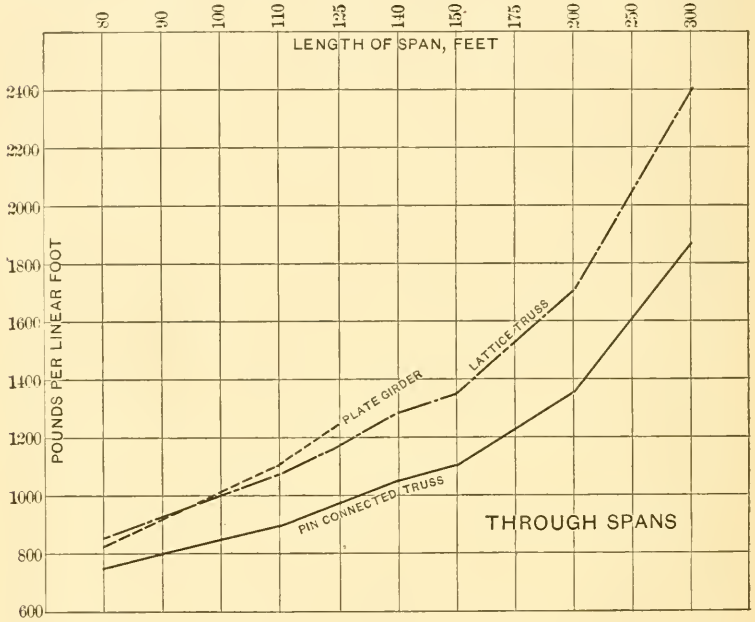


FIG. 6.

set aside first cost as the controlling feature in the consideration of alternate plans.

Using the general formulas for weights of bridges suggested by J. B. Johnson, M. Am. Soc. C. E., Fig. 6 has been calculated to show the weight per lineal foot of different types of bridges. Of course, these weights would vary with the different loadings assumed, and the formulas used are not claimed to be exact, but the results probably show the relative weight of the different types reasonably well.

From this it would appear that for a span of 200 ft. the pin-connected truss would weigh 20% less than the riveted truss, and for a

span of 250 ft. the difference in favor of the pin type would be 27%; hence it is likely that the limit of 200 ft., suggested by Walter Katté, M. Am. Soc. C. E., at which the pin-connected construction shall begin, is not too conservative. Mr. Cushing.

For the shorter spans there seems to be little doubt that rigid construction will become the general practice. In his last specification, Theodore Cooper, M. Am. Soc. C. E., extends the limits of rigid construction as follows:

Type.	Former Specification.	Latest Specification.
Rolled beam	16 ft. and under.	20 ft. and under.
Riveted plate girder	16 ft. to 70 ft.	20 ft. to 75 ft.
Riveted plate or lattice girder	70 ft. to 100 ft.	75 ft. to 120 ft.
Lattice or pin-connected truss	.....	120 ft. to 150 ft.
Pin-connected truss	100 ft. and over.	Over 150 ft.

One of the former objections to the riveted type of bridges was the difficulty in transporting intact such long and heavy loads, and the consequent large amount of hand riveting in the field of the detached parts. This difficulty is now largely overcome by the greater capacity of cars and more intelligent methods of loading girders, so they may move laterally to conform with the chords of curves over which they are passing. In this way girders over 100 ft. long have been transported without any trouble, for considerable distances over railways having heavy curvature. Such movements are entirely safe if a reasonable limit of speed is maintained by the train in which the cars are moved.

Though some railways in their late specifications still adhere to their former practice in limiting to 75 or 80 ft. the spans for which girders are required, even expressing a preference for pin-connected types of spans exceeding the latter length, the writer believes that for spans of 100 ft. and under, plate girders will eventually become general practice, while pin-connected spans of less than 150 ft. will rarely be built on railways having heavy traffic.

The author properly remarks that engineers of the present day should be thankful to those who, in the face of opposition, laid the foundation for the present system of iron bridge construction. Now, when the results of years of careful research by the members of the profession has been crystallized into formulas, tables, charts and so on, the use of which reduces the minutiæ of calculations so much, it is hard to realize the tedious labor necessary in early bridge designing. The profession owes much to those men who, like the author, first determined the course and then blazed out the way. It must be pleasant, indeed, for him to observe these monuments to his judgment and ability standing as mute but eloquent answers to those who opposed his efforts in the beginning.

Mr. Gray. GEORGE E. GRAY, Hon. M. Am. Soc. C. E.—The author is greatly interested by the discussion relating to early practice in bridge building. A few comments may not be out of place to complete history. The author's original designs, charts, strain sheets, and calculations for the iron bridges referred to, built on the New York Central Railroad prior to 1865, are still in his possession. Col. Carroll was his draftsman and assisted in making detail drawings, etc., and afterwards was entrusted with the supervision during construction of these bridges. He had but brief experience in iron bridge building before entering the service of the New York Central Railroad Company. Mr. Charles Hilton had in special charge the wooden bridges, buildings and other structures, but no experience in iron bridge building until the retirement of Col. Carroll, when that charge was added to Mr. Hilton's other duties. He could not be considered a pupil of Col. Carroll.

Mr. Hilton consulted the author in October, 1865, relative to the change of a plan previously prepared for a bridge contemplated over the Erie Canal, near Canastota. This change had been discussed at different periods, but the author objected to it, mainly because of the increased strain on the rivets, at the same time admitting the reduction of material. This latter was not considered an equivalent and the objection holds good to this day.

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No. 798.

GOVERNING OF WATER POWER UNDER VARIABLE LOADS

By M. S. Parker, M. Am. Soc. C. E.

Presented December 2d, 1896.

WITH DISCUSSION.

The government of water power under variable loads has always been considered a difficult problem under the most favorable conditions. Many operators of water-power plants where changes in load are great and sudden have found their government so uncertain and near the danger line that it was believed a few years ago that small electric street railway plants could not be successfully operated by water power. With large plants the change in load represents but a small percentage of the whole power in use, so that the variation in load is not so extreme as to cause serious difficulty in the government of the power. It is the extreme and sudden changes that cause trouble.

The modern ball governor, as used to regulate water-wheels, is satisfactory in its operation where the power used is fairly constant, but becomes entirely inadequate for the government of water power where

the changes of load are sudden and extreme. The author had this problem of the government of water power brought to his attention a few years ago and found little published data to assist him in solving it. The solution became a matter of experiment. The result of these experiments and the conclusions drawn from the investigation may be of some interest to the engineering profession.

The power to be governed consisted of a pair of 22½-in. Victor turbine wheels working under 40 ft. head. These wheels generated about 400 H.-P. on the wheel shaft, which is used in operating 6 miles of electric street railway, having a twenty-minute service. On this line are employed from four to ten cars daily, equipped with two 15 H.-P. single motors. The extremes of variable load are of daily occurrence. There are moments when with four or more cars in service the load is suddenly removed by the stopping of all cars at once, making a sudden change from a load of 120 H.-P. or more to no load on the generators.

This was the cause of frequent annoyance and expense due to the burning out of armatures, as the ball governor of the water-wheels does not act quickly enough to prevent racing of the wheels at times. A large fly-wheel roped with five 2-in. diameter ropes from the wheel shaft failed to hold the wheels always in check. When the wheel governor, assisted by the balance wheel, succeeded in checking the speed, as frequently occurred, the recovery of the necessary power to operate the entire load was necessarily slow in action, causing delay in the starting of the cars. These results are too well known to those who have had any experience in trying to operate a water power under extreme variable loads to need further notice. The water to operate the wheels mentioned is conducted from the head-works at the dam to the wheels through a penstock 9 ft. in diameter and 400 ft. long. The absence of a vent or standpipe on the penstock made the problem of government of the power still more difficult of solution. It has been the practice among hydraulic engineers, so far as the author is aware, to disregard length in penstocks in designing water-power plants. From the author's observation and experience it is shown that the shorter the column of water in the penstock, the easier it can be regulated or governed in flow at the wheel. In other words, in reducing the time of getting power from the water to a minimum where long penstocks are indispensable, it will add greatly to the facility of gov-

erning the water if a standpipe is placed on the penstock near the wheels to be governed, of a diameter equal, or nearly so, to that of the penstock. The vent pipes as generally used on such penstocks are entirely too small to be of any material service in governing the water power developed. It is readily understood that when the velocity of flow of the water in a long penstock is checked, time is required for the same velocity to be again acquired. The standpipe suggested for such cases acts as a governor and brings the actual head of water into effect in the minimum period of time. It acts as a reserve force to allow the water in the penstock to regain the required velocity.

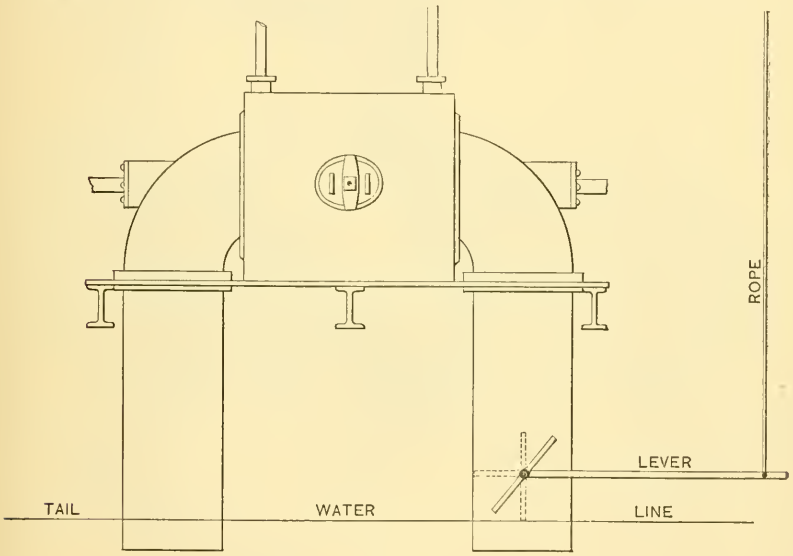

FIG. 1.

The power company had under consideration several electrical devices for relieving the machines of surplus current, but these were abandoned, either as being too expensive to be considered or as being insufficient in operation. A patented electric governor was obtained and has now been in operation for about two years and has proved successful beyond all expectations.

The governor was placed in position under a guarantee from the inventor to accomplish certain results or receive no compensation for the governor. He failed to accomplish the promised conditions, but the result was so highly satisfactory and such an improvement over

anything before tried that the company gladly paid for the governor. Some minor improvements since made have brought it up to the promised efficiency.

The electric governor consists of a gate regulator, a high-speed engine regulator and a common telegraph or gravity battery, with its

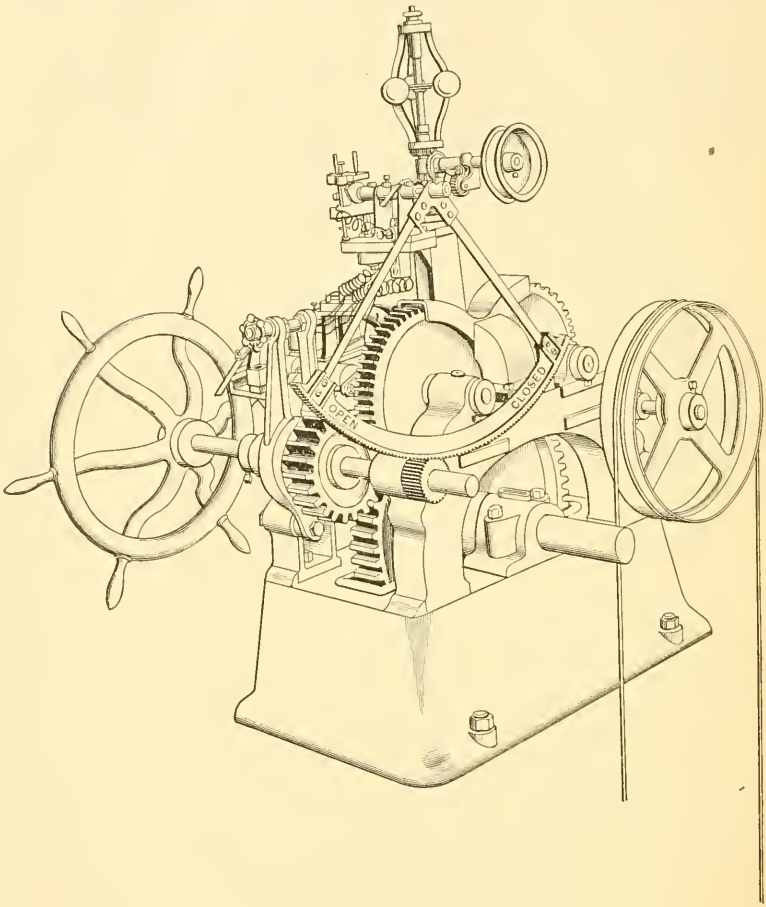

Fig. 2.

circuit. The regulator is powerful enough to control the wheel gates, and receives its power directly from the wheels. It is also so sensitive that the battery current will cause it to move the gates as desired. The engine governor is simply used as an indicator of speed, and as the indicator rises or falls it makes an electric contact, tele-

graphing the regulator which way to move the gate. There is no limit to the distance that may be between engine governor and gate regulator. Fig. 1 is a cut of the governing gate in use. This gate is placed in the draft tube, and is known as a butterfly or damper gate. To the gate axis, extending through the draft tube, is attached a lever, worked by means of a wire rope attached to a pulley on the regulator, the gate being opened or closed as the speed of the regulator increases or diminishes, the register gate of the turbines being left wide open constantly while the wheels are in operation. Fig. 2 is a general cut of the governor. The wire rope passes several times around the pulley shown on the right of the cut, one end of the rope

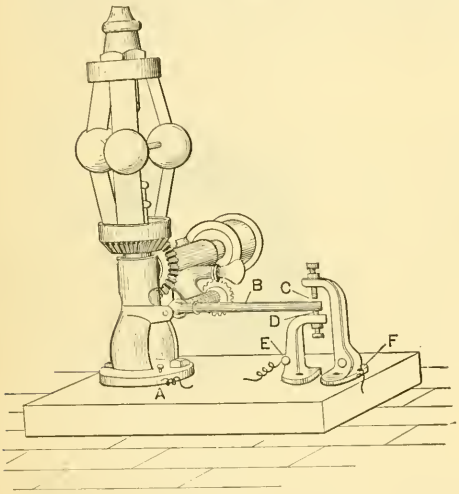

Fig. 3.

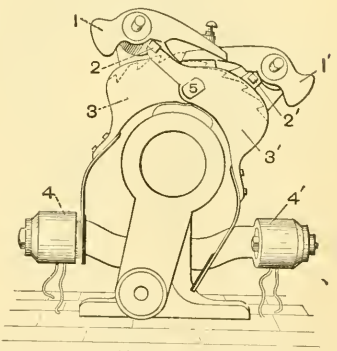

Fig. 4.

being attached to the lever of the gate in the draft tube, and the other end to a counter-balance weight. The end to which the counter-weight is attached was formerly made fast to the pulley. The substituting of a counter-weight for this arrangement is advisable, as it is a help to quick action, and relieves the machines of an unnecessary load in closing the gate.

Figs. 3 and 4 show the electrical connections of the speed governor and regulator pawls. The speed governor is belted to the shaft to be regulated, and a rise or fall in the speed of the shaft causes a corresponding rise or fall in the little lever *B*. The lever *B* is a portion of the battery circuit, and in falling makes or completes the circuit at

the contact *D*, which is connected by wire to magnet 4. Magnet 4 becomes energized and attracts armature 3, lowering lug 2, which action permits gravity to drop pawl 1 into the ratchet shown in dotted lines. The motion of the ratchet wheel opens the gates. This operation is instantaneous, and gives to gravity the advantage of time that is lost in the heavy slow-acting balls which must necessarily be used in mechanical water-wheel governors. A reverse of this process will close the gate.

"Gravity is the force from which we derive energy in water power. The energizing effect is constant as far as pressure is concerned. If more power is required from a water-wheel at any time it must necessarily come from one or both of the only two sources available under the existing conditions, namely, the existing pressure maintained dur-

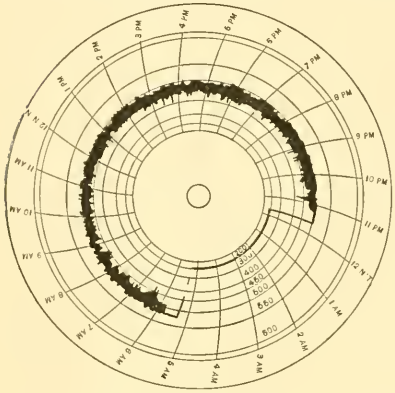

Fig. 5.

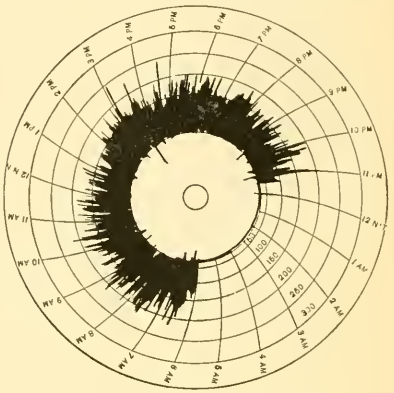

Fig. 6.

ing a longer time, or a greater area of pressure during the same time. Since it is impossible to maintain an even speed for fluctuating loads by the former source, we must resort to the latter. And since it requires time for gravity to energize or give motion to the increased quantity of water required for an increase of load, it is evident that most valuable time can be saved by opening the gates at the earliest possible indication of decrease of speed."

The foregoing in the language of the inventor correctly asserts the principle upon which this governor is constructed. He accomplishes this result by an extremely sensitive governor, the sole duty of which is to indicate variations of speed. The battery power serves simply to trip the pawls which throw the gate mechanism into action. Fig. 5 is an average voltage card for a day's run on the electric street railway. It is taken at random from the daily cards taken at the power

station. Fig. 6 is the recorded amperage for same day. These records do not fall much below the average records of the best governed engine work. This governor, as will be seen from the description, is not an expensive piece of mechanism. Its construction is simple. The expense of maintenance for the time it has been in service under the author's observation consists of the occasional renewal of the wire rope. While the author is not prepared to say that this is the best device on the market for the government of water power under variable loads, he can say that it is the best and least expensive device that has come to his notice, and that it has solved the problem of the government of water power under extremely variable loads in the instance herein cited. In his opinion there is no reason existing why water power cannot be successfully employed, where variable loads are the rule, by the use of electric governors. The conditions should be made as favorable as possible in original construction, and the electric principle applied to governing the gates will give satisfactory results in steady power.

DISCUSSION.

Mr. Hawks. A. McL. Hawks, Jun. Am. Soc. C. E.—There is a small water power near Olympia, Wash., which is used for milling purposes and also to operate an electric railway and lighting system in that city. The same pair of 60-in. wheels drives the railway and lighting generators, and the result is that the incandescent lamps flicker considerably, owing to the varying loads on the railway circuits. The water is taken directly from the falls and delivered within 50 ft. to the wheels. The ball governor originally tried as a regulator proved to be useless, so the governing is now done by keeping a man all the time at the entrance gate of the penstock. He has before him the voltmeter and ammeter of the circuit and five incandescent lamps, so that his eye will be attracted not only by the swinging of the needles, but also by the flickering of the lamps. As fast as a change occurs the headgate is opened or closed, the governing being done entirely in this manner. The work requires two men, who are paid $1 50 a day each, making the total expense of this system of governing over $1 000 a year. The manager of the works is so well satisfied with it that he refused the speaker's offer to supply a reliable governor which would operate automatically, for a sum equal to the semi-annual cost of the present method.

Mr. Smith. J. Waldo Smith, Assoc. M. Am. Soc. C. E.—With regard to the statements in the paper concerning the time needed to change the condition of motion in long penstocks, it may be said that observations on a 4-ft. pipe about 22 miles long have shown that a change of conditions at the lower end will affect the flow of water inside the pipe in less than a minute. The water starts and stops almost instantaneously with the opening and closing of the gate.

CORRESPONDENCE.

Mr. Frizell. J. P. Frizell, M. Am. Soc. C. E.—The methods and mechanism described by the author are capable, without doubt, of accomplishing what he claims, and were regulation the only condition to be fulfilled in the use of water power, this would be an advisable method of securing it. Economy in the consumption of water is, however, an indispensable condition in the use of water power, and it appears to the writer that the method described would be attended with very material sacrifices from this point of view.

The regulation of water-wheels by gates placed in the penstock or draft-tube has been adopted and practiced by engineers of standing. The writer has therefore thought it worth while to point out in some detail the nature and extent of the losses involved in such a system.

Mr. Frizell.

The wheel is the so-called Victor wheel, a pair of wheels on a horizontal axis. The head is 40 ft., the maximum yield of power 400 effective horse-power, the power in current use varying from that figure to practically nothing. Like all wheels, it is provided with a regulating gate, properly so called. The author introduces an additional gate, which may be called a throttle gate, in the draft-tube below the wheel. The conditions would be precisely the same if it were introduced in the penstock above the wheel. In this arrangement the regulating gate, or gates, of the wheel remains fully open at all times, the mode of regulation consisting in diminishing or increasing, according to requirement, the effective head acting on the wheel. The portion of the head excluded from operation on the wheel is employed in giving velocity to the water after it has passed the wheel. The writer will compare the quantities of water corresponding to different amounts of power in this system with those where the regulator acts on the regulating gate.

The makers of the wheel place the efficiency when running under full gate at 0.81. This is its efficiency under all conditions in the author's system. This fact tends to economy, while the diminution of the head tends in the opposite direction.

The quantity of water required for 400 H.-P. is—

$$\frac{400 \times 550}{40 \times 62.3 \times 0.81} = 109 \text{ cu. ft. per second.}$$

Suppose the requirement for power to be reduced to 300 H.-P. This would be furnished with an efficiency of about 0.77. In this condition the quantity, with regulating gate controlled, would be—

$$q = \frac{300 \times 550}{62.3 \times 40 \times 0.77} = 86 \text{ cu. ft. per second.}$$

To find the quantity corresponding to 300 H.-P. when controlled by throttling the draft tube, it is necessary to proceed as follows:

q = quantity of water discharged, in cubic feet per second.
h = head acting on wheel, in feet.

The two following equations may be written:

$$\frac{0.81 \times 62.3\, q\, h}{550} = 300. \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$q = 109\sqrt{\frac{h}{40}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

From which the following are obtained:

$$h = \left(\frac{550 \times 300\ \sqrt{40}}{109 \times 62.3 \times 0.81}\right)^2 = 33.02. \ldots\ldots \quad (3)$$

$$q = 109\sqrt{\frac{33.02}{40}} = 99 \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Mr. Frizell. That is to say, to obtain 300 H.-P. by controlling the regulating gate would require 86 cu. ft. per second. To obtain the same power by the author's method would require 99 cu. ft. per second.

Performing the same computations for 250 H.-P., it will be found that this could be obtained by controlling the regulating gate with 78 cu. ft. per second, and by throttling with 93 cu. ft., the effective head in the latter case being 29 ft. With 200 H.-P. the figures would be 70 and 86 cu. ft. respectively, the head in the latter case being 25 ft. With 150 H.-P. the efficiency of the wheel is assumed at 0.50. The quantity in the first mode of regulation would be 66 cu. ft. per second, and in the second 79 cu. ft., with an effective head of 21 ft.

This mode of computation is not strictly correct. To avoid intricacy, the efficiency of the wheel at three-fourths, five-eighths, one-half and other parts of the maximum power has been assumed the same as the efficiency at three-fourths, five-eighths, one-half and other parts of the maximum discharge. A true computation would show the difference in economy between the two modes of regulation to be greater than here appears. It is sufficient, however, to show that regulation by throttling is not advisable where economy in use of water is of importance.

The writer's object in this criticism is simply to point out the inherent and unavoidable defects of the proposed mode of regulation. He will offer one further remark upon the statement quoted from the inventor, viz., "it requires time for gravity to energize or give motion to the increased quantity of water required for an increase of load."

The writer must pronounce this an unqualified error. In a pipe of the length indicated, filled with water under some pressure, if the wheel gate is conceived to be instantaneously opened, the starting of the water through the gateway would be absolutely coincident with the opening of the gate. The entire contents of the pipe would not start simultaneously. A change of pressure in such a condition is propagated through the pipe with the velocity of sound in water; about one-twelfth of a second would elapse from the starting of the gate before the water commenced to move at the receiving end 400 ft. distant. The discharge during this interval would be maintained by the expansion of the water and contraction of the pipe consequent upon the release of pressure.

Mr. Replogle. Mark A. Replogle, Esq.—The writer has been making a special study of the problem of governing water power under variable loads for some years past, and has necessarily had some varied experience in this line. He has made a detailed study of the practice of using long closed flumes and penstocks, and, in his opinion, too little attention has been given by engineers to their effects in the matter of government or wheel regulation.

Mr. Replogle.

The draft-tube governing appliance referred to in the paper is evidently an expedient to overcome, or partially so, the evil effects of a long horizontal penstock. Water being practically inelastic, it is plain that for every increase or decrease in quantity entering the wheel gates, there must be a corresponding increase or decrease in the rate of flow throughout the flume or penstock. Wheel plants have been designed and built where it requires the full power of the head for many seconds to raise the encased horizontal body of water to the velocity necessary to furnish the power required for an increase of load, such as is required in starting one or more cars on the line ; and since the motorman takes the power, rather than leaves an order for it, it must be supplied from the revolving machinery until the gravity effects are available for power purposes at the wheel gates. The result is that the speed will drop until balanced by gravity, which balancing can only be done at the expiration of the time necessary for gravity to impart power enough to the great horizontal mass of water to give it the proper velocity at the wheel gates. A water-wheel receives its power by stopping the water to which gravity has given motion, and the water must enter the wheel at a proper velocity in order to yield its fullest efficiency of power. After increasing the opening of a wheel gate at the end of a long pipe or flume, the first effect is a reduction of the velocity in the ratio that the gate area is increased, and this reduction in velocity is lowering the power effect of the water on the wheel, making the first effect after moving the gates the opposite to that desired. This first bad effect, added to that of lost time in changing the velocity in the closed flumes, makes them very undesirable from a governing point of view.

The writer's experience has led him to believe that the discharge gate described in the paper decreases one-half the time in getting the gravity effects where long flumes must be used, as experience shows that about one-half of the water must pass through the wheel to bring it to speed, while only the latter half must be added to furnish the maximum power. This is accounted for by the changes made in the head, by backing the water up in wheel, and by the fact that a full efficiency cannot be had unless the water enters the wheel at a proper ratio of speed.

The experience gained during the development of a 35-mile electric water-power transmission plant in the Rocky Mountains has gone far toward maturing the writer's views concerning long pipes as feeders to water wheels. In this plant the head is 1 410 ft.; the supply pipe is about 3 800 ft. long and 20 ins. in diameter; the static pressure at the wheel gate is 610 lbs. per square inch. Two safety or relief valves were at first provided near the wheels, to insure safety to the pipe in the event of a sudden stoppage of a wheel-gate opening. Experience showed that there was a possibility of damage even before the inertia

Mr. Replogle. of the relief valve weight could be overcome; it was also noticed that when the relief valve operated properly, it would remain open until the pressure was relieved in its vicinity, then it would close. The decrease of pressure at this point would allow a flow of water toward the relief valve, caused presumably by the elasticity of the pipe, and the valve would open a second time more violently than the first. The commotion in the pipe kept increasing with each succeeding opening, until the valve had to be held down to prevent damage to the pipe. This and subsequent experiences proved to the engineers in charge that it was dangerous to trust to the relief valves for safety; hence they were blocked. All valves were provided at once with threaded stems, so as to require considerable time in opening or closing. Before this provision was made another incident occurred, which was expensive as well as interesting. One of the wheel gates was suddenly opened by accident, and the pressure gauge showed a reduction of several hundred pounds after a very short period of time. This induced the operator to close the gate quickly. It is said that the pressure gauge registered 1 000 lbs. almost immediately. The steel pipe burst at a point 700 ft. above the power-house. This presumably was the meeting point of the water in filling the vacuum caused by opening the gate too suddenly. Several hundred feet of the upper portion of the pipe lay in an almost horizontal position; hence the water contained in it would not start so quickly as the water in the more vertical portions. Immediately after the burst occurred, the horizontal portion of the pipe collapsed, as the water left it through the break 700 ft. below.

No attempt was made to govern this power plant by wheel gates. Tangential wheels with deflecting nozzles were used, and these were deflected by an electric device similar to that described in the paper. It might be added that the water from the deflecting nozzle very quickly cut away the solid granite bottom of the tail-race; plank floor lasted less than twenty minutes, and boiler plate lasted only a few days. At present cast-iron blocks are furnished at intervals of a few weeks each.

A unit of power in this plant consists of a 500 H.-P. tangential wheel attached to the same shaft as the armature of a three-phase dynamo. For assistance in regulation, there is also a fly wheel keyed to the same shaft. The shaft at normal speed runs 600 revolutions per minute. The power storage of the revolving parts, at normal speed, is about 9 000 H.-P. for one second of time. This is enough to insure power for the sudden changes in speed, as it will carry an increase of 100 H.-P. nearly four seconds before the speed has dropped 2 per cent. This allows ample time for the governor to shift the nozzle to a point necessary to add the increased power demanded, and prevents unsatisfactory changes in speed. The governor is designed to operate in conjunction with the power storage of the plant.

M. S. Parker, M. Am. Soc. C. E.—The manager of the electric station, referred to by Mr. Hawks, evidently does not put much faith in the automatic governing of water-wheels. His method of governing wheels, however antiquated, is the only illustration of wheel governing mentioned in the discussion. Mr. Parker.

Theoretically the author agrees with Mr. Smith and also with Mr. Frizell as to the movement of water in pipes, but in governing water-wheels, from the experience of himself and others with whom he has spoken upon the subject, the use of short penstocks where practicable, and large vents where long penstocks are indispensable, is to be advised. Mr. Frizell is correct in his conclusions as to the lack of economy in the use of water with the throttle gate, as mentioned in connection with the governor described. This, however, is of little importance in the instance cited. There is little storage capacity for impounding water. The daily flow of the river represents the maximum amount of power sold to consumers. In the instance mentioned the company pays for the maximum quantity of power used. Most of the water powers in the northwest are similar to this in lack of storage capacity. The problem to be solved in the case cited was the governing of the wheels, and not economy in the use of water. The water-wheel manufacturers fail to govern the wheel gates satisfactorily for variable loads. The equations given by Mr. Frizell solve the problem of economical use of water, but they do not substitute a governor for the gates of the wheels to control the variable load and realize the economy mentioned. Thus he gets back to the original problem.

As a further example of the government of water power under variable loads the author will give a brief description of the method employed for the control of a large unit of power upon a single shaft. The plant consists of a pair of 57-in. cylinder gate turbine wheels operating under 42-ft. head, running two direct-connected electric generators carrying a load of 9 000 amperes at 180 volts. The conditions are such that the entire load may be suddenly removed from the machines through unforeseen complication of circumstances. To avoid the disaster consequent upon such a condition, the following system for control of the power is in operation: A high-speed engine governor, with an electric connection similar to that described in the paper, Fig. 3, is operated from the wheel shaft. When the shaft exceeds a certain speed, the governor acts automatically, opening a cock in the draft tube, breaking the vacuum and losing thereby 16 ft. of head, acting at the same time to start a small motor used for opening and closing the gates. No time is lost through the attendant not being near to start the motor. The gate being closed, the gear is automatically thrown out. Beside the foregoing precautions, a water coil pipe is connected from the head-race to the tail-race. This coil is of sufficient length to carry off an electrical current equivalent to

Mr. Parker. about 800 H.-P. The current is taken from the main conductor in case of the load being removed as mentioned. These combined precautions for the control of this large unit of power under the conditions in which it is used appear from trial to make the control absolutely safe.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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No. 799.

THE UNDERPINNING OF HEAVY BUILDINGS.

By Jules Breuchaud, Assoc. Am. Soc. C. E.

Presented January 6th, 1897.

WITH DISCUSSION.

This paper is a description of a novel method recently adopted for the support of heavy buildings.

The first instance of which mention will be made is in connection with the foundation work for the Commercial Cable Building, twenty-one stories high, at Broad and New Streets, New York City. The lot occupied by the new building is 45 ft. wide on Broad Street and 55 ft. on New Street, and is 160 ft. in length.

The plan required an unusually deep excavation which was to contain two stories below the level of the street, the total depth from the sidewalk to the under side of the concrete floor being 30 ft. on Broad Street and 36 ft. on New Street.

The lower story and a part of the next, being below the water level, had to be made water-tight, and in order to obtain that result the plan included, on each side of the lot, a continuous line of rectangular

caissons to be put in place by the plenum pneumatic process. Other caissons, circular in form, were also sunk in the central portion of the lot for the support of the middle rows of columns. There are 39 caissons, including those which are rectangular and circular.

All these caissons, the rectangular ones generally 9 x 18 ft. and 6 x 14 ft., and the circular ones from 8 ft. to 9½ ft. in diameter, were sunk to the underlying ledge which was found to be from 45 ft. to 50 ft. below the sidewalk. Fig. 1 shows the arrangement of all the caissons. The original soundings indicated that the surface of the rock was at a higher elevation, but actual excavation showed that it was lower than expected, and that an important layer of hard-pan from 5 ft. to 14 ft. in thickness must be gone through before rock could be reached.

The contract for the foundations contained the usual provision making the contractors responsible for any damage to adjacent buildings, resulting from their operations. This made it necessary to devise means for supporting the buildings, while the depth to be reached and the necessity for economizing space, where so many caissons and their accompanying coffer-dams had to be handled, made it important that as little room as possible be occupied by the supports necessary to maintain the surrounding buildings.

As compared with other work of the same class heretofore executed in that vicinity, the problem of supporting the adjacent buildings was unusually difficult in this case, as the plans provided for the placing of the rectangular caissons almost contiguous with one another and exactly on the boundary lines of the lot, an arrangement which had not been previously attempted.

The attention of the author had already been called to the fact that considering the increasing height of the buildings which are now being erected for business purposes on comparatively small areas, a limit would soon be reached beyond which it would not be economical, or even practicable or safe, to use timber supports, even of such special and ingenious design as have been recently adopted for such purposes.

The peculiar conditions under which the work had to be done in this case led to the conclusion that it would be desirable to resort to such devices as would leave the limited space at hand entirely free from interference, and open at all times for the free handling of the pneumatic, hoisting and other plants, for the movement of bulky caissons

and for placing them strictly on the boundary lines of the lot. This latter result was literally accomplished, the rivets of the steel caissons in their downward progress leaving, in many instances, their marks on the brick surfaces of the adjacent walls.

The method followed consisted of placing vertical iron supports directly under the walls to be supported in the following manner:

After determining the number of supports necessary for carrying the superincumbent weight, a vertical slit was cut into the wall from the bottom upward, for a distance depending on local circumstances, generally from 10 ft. to 12 ft., the slit being of such a width as would amply accommodate the pipe which had been determined to be sufficient in diameter for each case. On the top of that slit a short transverse horizontal cut was made, in which one or more iron I-beams

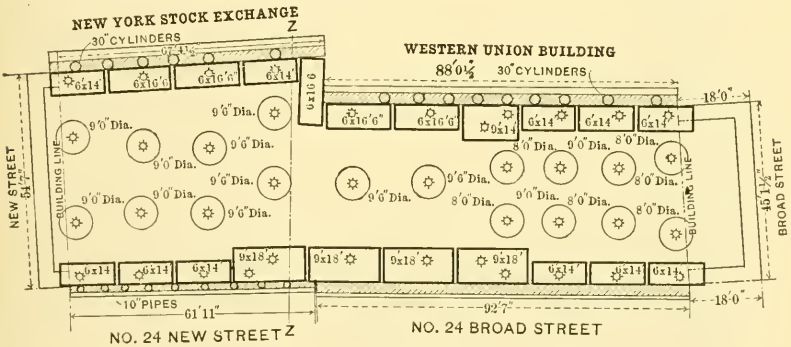


FIG. 1.

were built. The iron column or pipe which was to support the wall being divided into pieces of proper length, which could be either screwed together or united by means of bolted interior flanges, the first length was placed on end on the ground in the slit of the wall. Blocking being then placed on the top of the pipe, a jack was inserted between the pipe and the short I-beams built on the top of the slit, and either by simple pressure or with the aid of a water-jet, the first pipe was pushed down, by alternate jacking and blocking, to its full length. Next, a second piece of pipe was fastened on top of the first, and the sinking operation was resumed until another pipe could be added to the second, and so on until the pipe had reached bed-rock, or such other support as was sufficient.

The top of the highest pipe was left at about the level of the bottom of the wall, in which another set of short horizontal I-beams was

built, reposing on the top of the pipe. Vertical beams or columns were then firmly wedged between the two sets of horizontal I-beams, and the slit in the wall was filled up with brickwork. These vertical beams were used to avoid the compression which would otherwise occur in the fresh masonry built in the vertical slit.

Only one or two supporting pipes were, obviously, driven at a time, in order to avoid excessive concentration of weight on the other parts of the foundation while the pipes were being sunk.

The first trial of this method was made under the small building at the southwestern corner of the lot, it being desirable to proceed with caution. This building is only four stories high, but its brick wall was supported on a stone foundation of the worst description, 24 ins. thick, it being composed of small stones without bond, laid in so-called mortar without cohesion, which, at many places, could be easily blown off. The importance of keeping the building uninjured was increased by the fact that a restaurant business was conducted in the basement, and that an interruption of it would have caused a serious pecuniary loss to the contractors, who, as before stated, were held responsible for the proper maintenance of the adjoining buildings.

Considering that the distance of the bottom of the foundation wall of that building was 33 ft. from the hard-pan on which the supporting pipes were carried, and 23 ft. from the bottom of the cellar excavation intended for the new structure, the case required careful handling. Notwithstanding the small weight of the building, nine pipes were used on a total length of 57 ft. They are heavy steam pipes 10 ins. in diameter, $\frac{3}{8}$ in. thick, having a cross-section of 12 sq. ins., and weighing about 40 lbs. per lineal foot. They were sunk in lengths of 5 ft., connected together with outside couplings and butt joints. Every alternate pipe contained a smaller interior one, placed so as to break joints, the annular space between them being filled with Portland cement grout. All the pipes were ultimately filled with Portland cement concrete. Each pipe was driven into the hard-pan to a firm bearing by working the jack to its full capacity of 60 tons, which is more than the weight that each pipe has to carry. No movement of any kind occurred during or after the sinking of the pipes.

The success attending this preliminary operation led to the adoption of the same method for the support of the buildings on the north side, the Western Union and Stock Exchange Buildings, with such

modifications and improvements as were rendered necessary by the greater weights of these structures, the Western Union Building being seven stories high and the other less.

The Western Union Building is built on piles extending about 17 ft. below the base of the walls, the points of the piles being consequently a few feet above the bottom of the new excavation. Nine pipes were sunk to support it. In this case it was found desirable to extend the supporting pipes to the rock bottom, thus making it necessary to force them through many feet of hard-pan, which could not be dis-

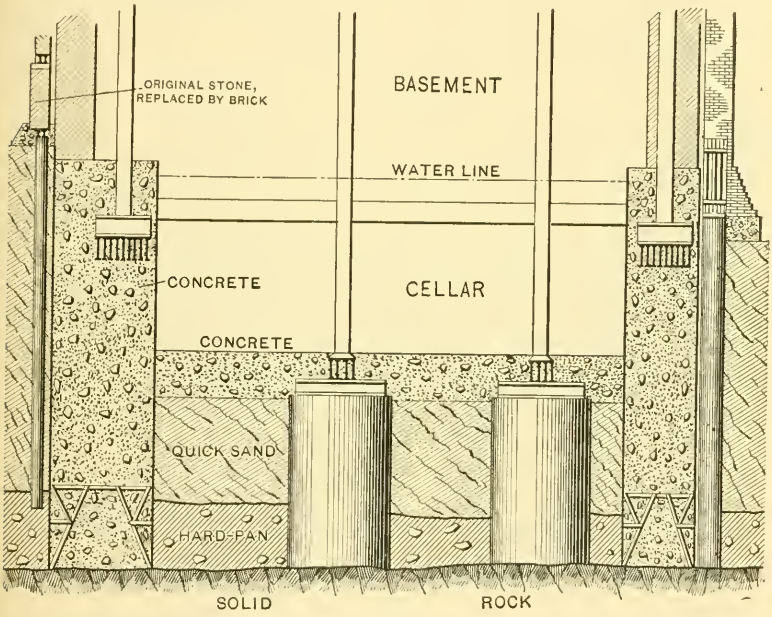


FIG. 2.

placed by jet and in which boulders might be found in the path of the pipes. In order to overcome these difficulties and to render it possible to level up the rock bottom on which the pipes were to rest, the pipes were made of cast iron, 28 ins. in interior diameter. This size made it practicable to send a man down for the purpose of excavating the hard-pan by hand in and under the edge of the pipe, of preparing intervening boulders for blasting, and of preparing the rock bottom when unsound or sloping and firmly wedging the bottom of the pipe thereon. Those operations, owing to the presence of water

in the ground, had to be carried on in compressed air, a portable and easily connected air-lock being provided for the purpose.

One of the lower pipes having been injured by forcing it down past a large boulder, the rest were subsequently made of riveted steel plates. Although boulders were encountered and blasted, and, in several instances, piles had to be extracted on account of their projecting into the lot of the new building, no serious difficulty was found in preparing for and sinking all the pipes, which were afterwards filled with concrete. Generally, two men, alternately jacking and blocking, were sufficient to drive the pipes, when once placed. No movement occurred in the Western Union Building.

The foundation of the Stock Exchange was similarly treated, six supporting pipes being used on a total length of 68 ft.

The next application of the same method was at the northwest corner of Cedar and William Streets for the support of the Stokes Building, a heavy structure, 11 stories high, pending the preparation of the adjoining foundation for the Queen's Insurance Building.

The Queen's Insurance Building is supported on pile foundations carrying grillages of steel beams which support the columns. The piles were cut off 1 ft. below the natural water level at the site, or about 18 ft. below the street level. The earth was excavated 1 ft. below the cut-off, and the concrete floor, 4 ft. thick, laid over the entire site.

The material at the site is of the same general character as often found elsewhere in the lower part of New York City, being quicksand underlaid by hard-pan and bed-rock. The preliminary borings indicated the existence of bed-rock 30 ft. below floor level.

The foundations of the Stokes Building are spread on the surface of the sand without supporting piles, and are estimated to carry 45 tons per lineal foot of wall. Unfortunately, when this building was constructed, the base of the foundation was placed about 2 ft. above the cellar floor of the adjoining building, now removed to make room for the construction of the Queen's Building (see Fig. 5). It was believed that the concussion of driving piles for the foundation of the Queen's Insurance Building would cause a flow of quicksand from underneath the wall of the Stokes Building, and consequently damage the structure.

The columns for supporting the Stokes Building are of cast iron, 33 ins. in exterior diameter and $1\frac{1}{2}$ ins. thick. When the work of placing

them was taken in hand, it was found that the borings were misleading, and the material supposed to be bed-rock proved to be firm hard-pan of considerable depth, in fact the first column was driven into it a distance of 16 ft. without finding any indication of rock. To persist in the attempt to reach bed-rock would have entailed an expenditure of a large amount of time and money without commensurate results, and it was decided to found the pipes on hard-pan. This material, being very compact, is capable of carrying a great load, especially at a considerable depth below the surface; however, as its limit of bearing

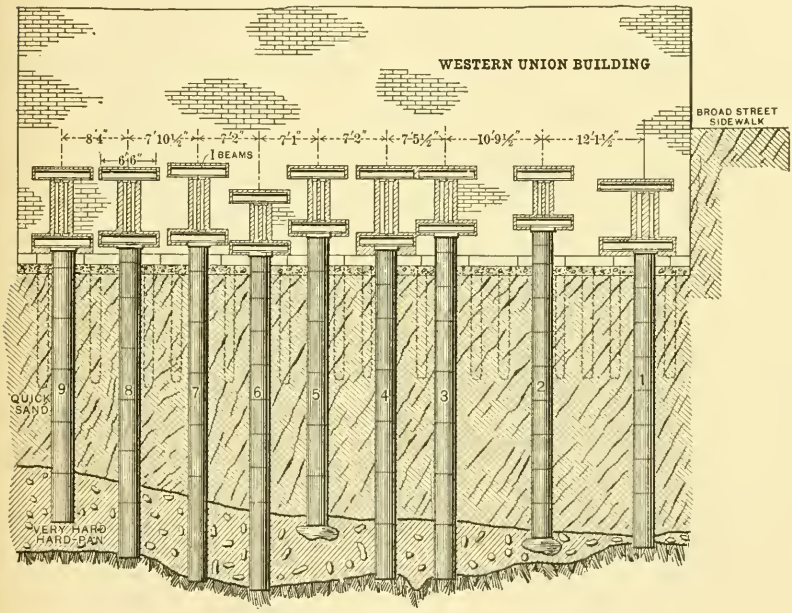


FIG. 3.

capacity is unknown, it was thought prudent to enlarge the base of the column by excavating outside the cutting edge and placing an annular steel ring on which the cutting edge was to rest. This ring, which extended 3 ins. outside the column and 4 ins. inside, was in sections and was composed of plates 1½ ins. in thickness.

The number of cylinders was not increased on account of the change in the foundation, and the pressure on the enlarged base, without deduction for friction on the sides of the columns, was in the neighborhood of 40 tons per square foot, which is, of course, much greater than

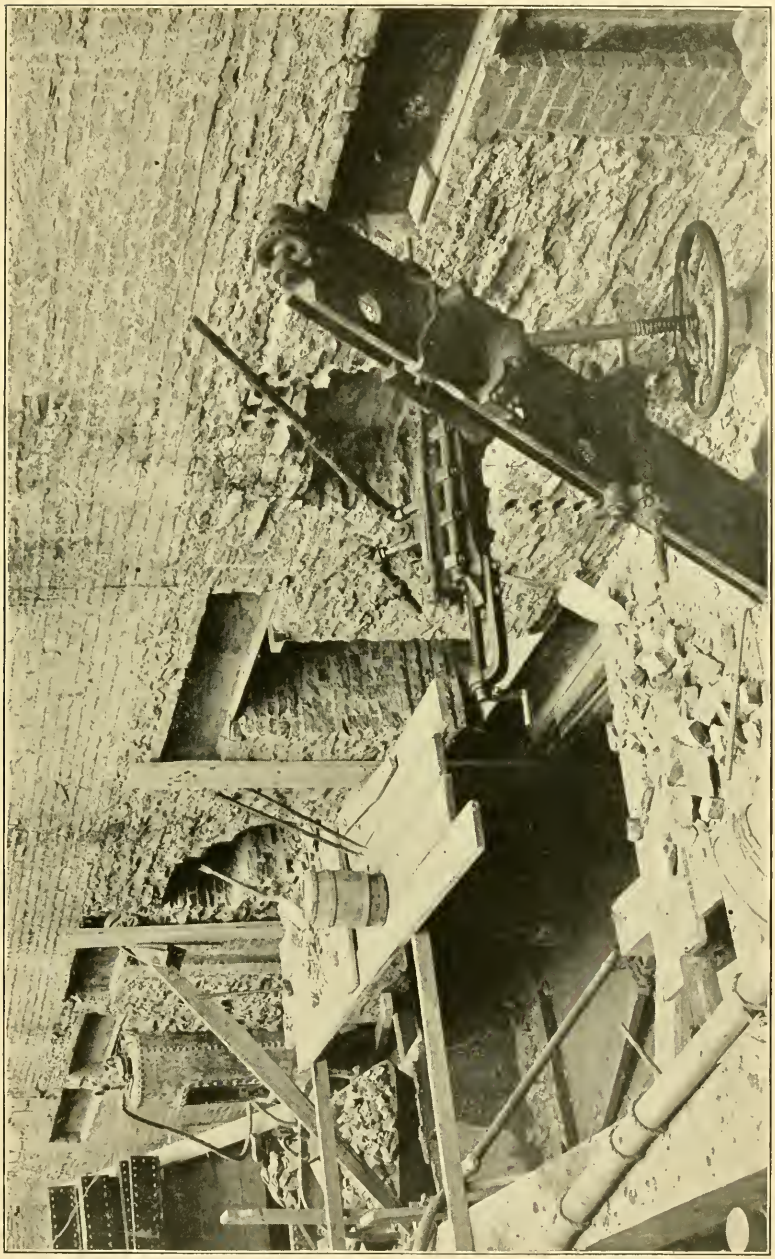
would be placed on masonry of the best character above ground. With due allowance for friction on the sides of the columns, the net load is supposed to be about 36 tons per square foot. Both these figures are doubtless in excess of the actual load, as the old foundation continues to bear some indeterminate part of the weight it formerly carried.

This work, including seven columns 33 ins. in diameter, was completed in seven weeks, without mishap of any kind, and the numerous piles for the new building were subsequently driven without injury to the Stokes Building.

Another high building, at the northwest corner of Wall and Nassau Streets, was also supported by similar means, the columns in that case being thirteen in number and made of lap-welded steel pipes $\frac{3}{8}$ in. in thickness and 16 ins. in diameter. This work was, it is reported, carried through successfully.

Referring to the illustrations (Fig. 1) gives the plan of the Broad Street foundation, showing the position of the 39 caissons and of all the pipes sunk under the walls of the adjoining buildings. Fig. 2 is a cross-section at a point where the lot widens. Fig. 3 shows the elevation of the rock bottom, the depth of hard-pan, and the position of all the supporting pipes. Fig 4 is a section of the supporting wall at one of the columns under the Western Union Building. Fig. 5 is a section of the wall of the Stokes Building, showing one of the supporting columns. Plate I is a view of the south wall of the Western Union Building, showing various phases of the operations for placing the supporting columns. Beginning at the right, the first, fifth and seventh columns are in place, and the operation completed. For the second and fourth, the cutting of the vertical slit is being made, close drilling being resorted to in this case, owing to the great hardness of the brickwork. At the third column the two sets of horizontal beams are in place, leaving only the vertical cut to be filled. The sixth column carries the air-lock while it is being sunk into the hard-pan.

Although the author does not wish it to be understood that the method above described is recommended as of universal application, he believes that in many cases, especially when the weights to be carried are great, and when the character of the ground is such that it becomes desirable to transfer the weight of the building to a deeper and



harder foundation, the new method is safer than those heretofore used and that it gives security economically. It has the advantage of leaving the ground which is to be built upon free from obstructions, thus preventing the costly and risky practice frequently resorted to of

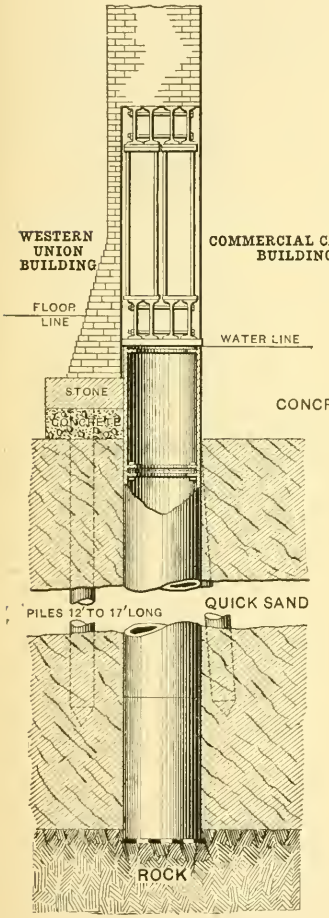


Fig. 4.

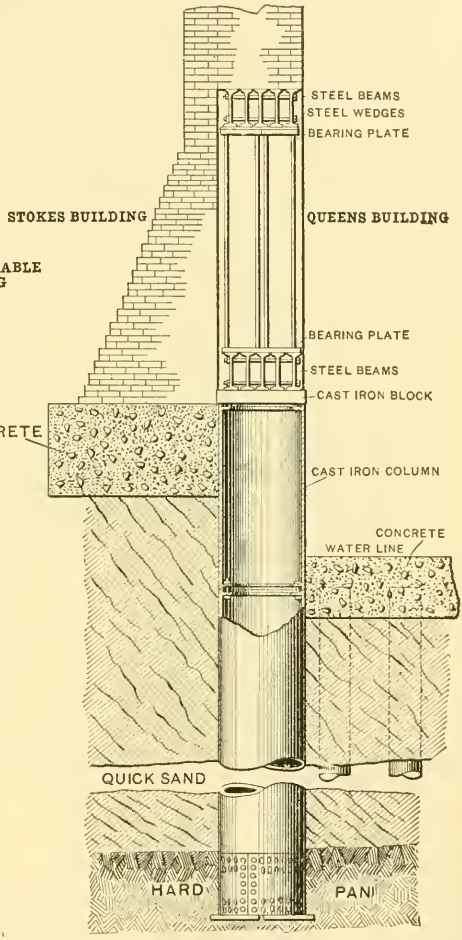


Fig. 5.

shifting the artificial supports during construction. The absence of interference with the inside of the adjoining buildings would often be a sufficient incentive to the adoption of this method; a lasting benefit can also be secured from the fact that the adjoining buildings remain

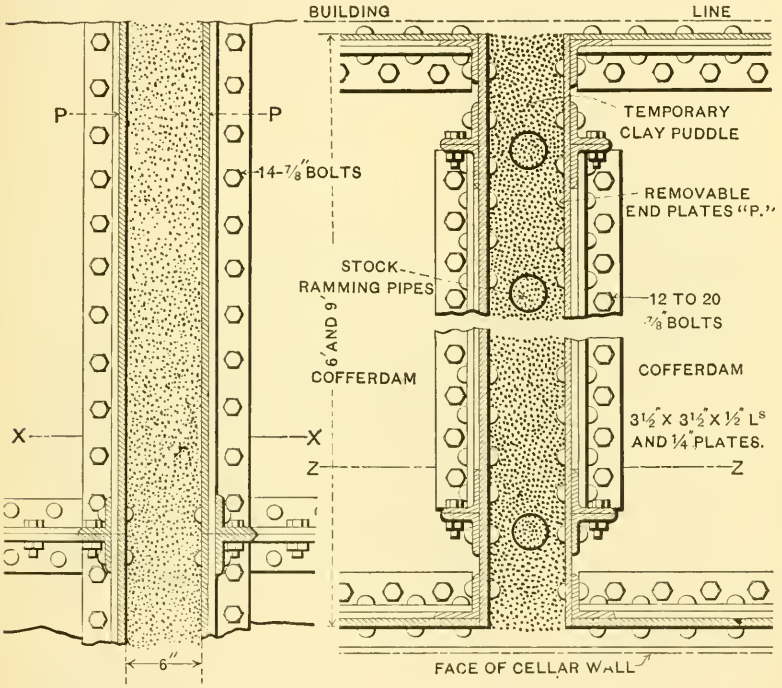
rigidly supported, thereby avoiding the usual, although often small, movements which follow the removal of the artificial supports used during the period of construction. Although other applications of the method may obviously present themselves in the general field of construction, the author prefers to leave others to draw their own conclusions, his object being only to describe the work done.*

The architects and consulting engineer for the Commercial Cable Company and Queen's Insurance Buildings were Messrs. Geo. Edward Harding & Gooch and John Bogart, M. Am. Soc. C. E., respectively. The contractors for the foundations were Messrs. Arthur McMullen & Co., of which firm the author is a member. In the execution of the work, the use of underpinning columns was devised by the author. The services of John F. O'Rourke, M. Am. Soc. C. E., were secured in the preparation of the preliminary plans and estimates for the Commercial Cable Building work, and the services of Alfred Noble and T. Kennard Thomson, Members Am. Soc. C. E., and Mr. Byron Goldsboro, superintendent, were secured for the operations on the Commercial Cable and Queen's Insurance Buildings.

* It has been thought unadvisable to burden this paper with too many details of construction, but if further information is desired, a detailed description of the foundations of the Queen's Insurance Building will be found in the *Engineering Record* of August 8th, 1896.

DISCUSSION.

THOMAS CURTIS CLARKE, Past-President Am. Soc. C. E.—The paper lays before the Society the development or evolution of a new branch of civil engineering. The shoring of buildings because of excavations made beside them is a very old process, familiar to all engineers, but the depth of foundations and the want of room incident to the construction of modern lofty office buildings are such that the author found it necessary to introduce entirely different methods in such Mr. Clarke.



VERTICAL SECTION Z-Z. FIG. 6.

PLAN AT X-X. FIG. 7.

work, changing it from a mechanical craft to civil engineering. He made it scientific construction, which is civil engineering.

FRANK W. SKINNER, M. Am. Soc. C. E.—While the engineer who follows a successful precedent may be entitled to great credit for able construction and for accomplishing a difficult undertaking safely, he who establishes his own precedent, and that under particularly difficult circumstances, is certainly entitled to the greatest credit that can be awarded to an engineer for his construction. The author's method of underpinning foundations marks a new era in the very difficult work Mr. Skinner.

Mr. Skinner. which has become prominent within the last decade, and bids fair to be one of the important factors, if not the leading factor, of future construction in steel work. In the important engineering work connected with the foundations described in the paper, there were many features of interest which were not mentioned by the author. One problem submitted to the contractors was the construction of a large entirely water-proof cellar more than 15 ft. below the ground-water level. The rectangular caissons along the sides of the lot were extended above the water line by iron coffer-dams, set so close together as to form long side walls, and subsequently filled with concrete. They could not be sunk in contact, and a 6-in. space was left between adjacent caissons, which had to be temporarily calked in some way. It was

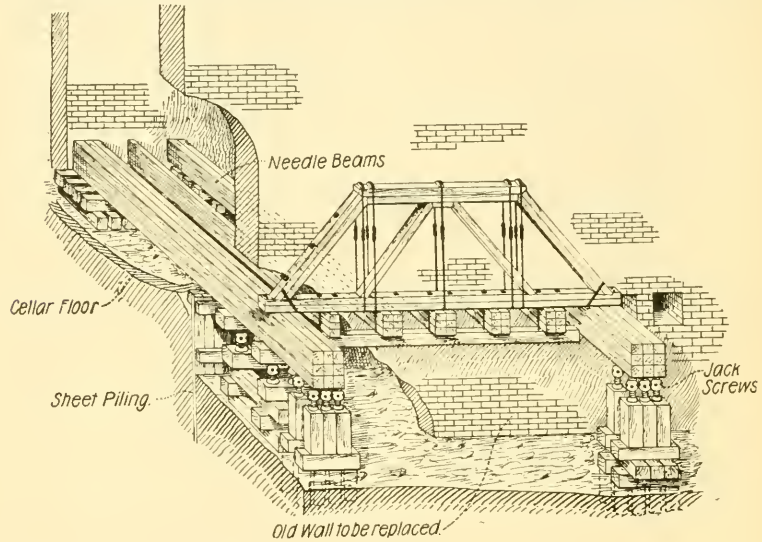


FIG. 8.

determined to do this by means of clay puddle forced into place by the stock-ramming process. A 3-in. pipe 35 ft. long was sunk at three successive points in one of the spaces by means of a water-jet furnished by a 1½-in. pipe ending in a ½-in. nozzle lowered inside the larger pipe. When the latter was sunk into place, the inner pipe was removed, and the larger one filled with cylinders of kneaded clay cut by means of a special tool. When the pipe was full, the clay was forced out by a 2⅔-in. ram driven down by the hammer of a pile-driver. After the pipe had been filled three or four times, the ram had to be tapped a little in order to make it sink under the weight of the hammer. In this way from 3 to 5 cu. yds. of clay was inserted in each space. The pressure produced was so great as to shear the bolts in a number of the

flange splices of the removable end plates, *P P*, of the coffer-dams (Figs. 6 and 7). Mr. Skinner.

The manner of removing the débris from the bottom of the 10-in. pipes shown in Fig. 1, after the hydraulic jet had been used, was interesting. A long piece of gas pipe had attached to one end a sheet-iron cylinder which was provided on its bottom with inclined radial cutting edges like those of an auger. This was twisted into the material until full, and then lifted to the surface and its contents removed. When the pipe was cleaned out it was filled with concrete, the bottom 6 ft. being placed under water.

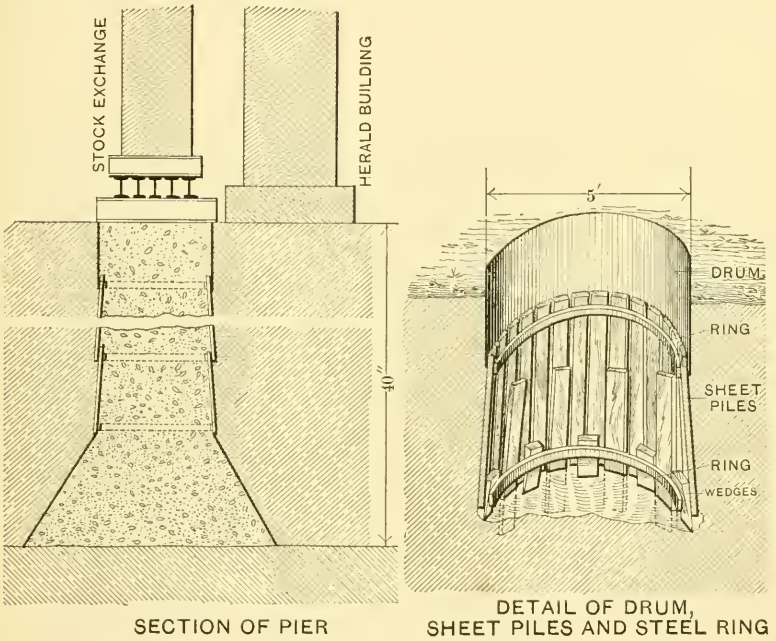


FIG. 9.

It has been mentioned that one of the advantages of the author's method of underpinning is the trifling obstruction it offers to the progress of work and the slight injury it causes to adjoining buildings. This is well shown by comparing it with one of the most ingenious expedients of the old method of shoring, which is illustrated in Fig. 8. In the construction of the foundations of a high office building in New York City, it was necessary to utilize all the site for conducting the operations on the new structure, and, indeed, a deck was built over it so as to gain additional working room. An L-shaped building bordered two sides of the site, and its walls had to be supported during the construction of the new foundations. A series of holes were cut

Mr. Skinner. through the wall just above the level of the basement, and built-up needle beams were inserted through them. These beams were formed of 12 x 12-in. timbers arranged as shown. The ends inside the basement were supported on distributing piers of cribwork, while the other ends were carried by a bearing beam hung from the bottom chord of a wooden truss. Each end of the truss was supported on heavier composite needle beams, which rested on cribwork at one end and at the other on blocking and jackscrews carried by piles, as shown in the cut. The rods by which the bearing beam was hung from the truss were provided with nuts which permitted some adjustment of the needle beams to be made. The truss was flush against the wall and projected from it perhaps 18 or 20 ins.

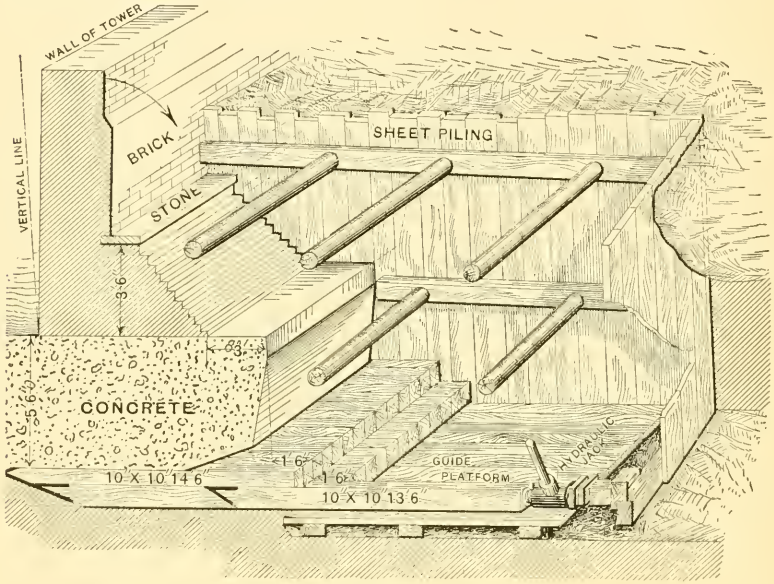


Fig. 10.

Eventually the cribwork at the outer ends of the end beams was replaced by small groups of piles which occupied very little of the ground space and left all that portion between them entirely unobstructed.

In the construction of the Stock Exchange Building in Chicago it was feared the excavation would injure the wall of an adjacent building, so it was underpinned in an unique manner by carrying down a series of intermediate piers from the wall to the hard stratum below. Cylindrical steel drums 5 ft. in diameter and about as high were set in cavities below the wall, and the enclosed earth removed. Short sheet piles were then driven under the bottom edge of the cylinder and the earth within this piling excavated nearly to its foot. Then a heavy

steel ring was set horizontally and another set of sheet piling driven between it and the first, as shown in Fig. 9. The earth within this set was excavated and the process continued until a well about 40 ft. deep was sunk to the hard bottom. The well was finally enlarged and filled with concrete. Mr. Skinner.

The method adopted to reinforce a long wall in Calcutta, India, affords another example of interesting foundation work. The High Court Building in that city has a front wall 379 ft. long and a tower of 45 ft. wide, and probably above 90 ft. high. It was built on the alluvial soil of that locality, and after twenty-five years was found to have settled unequally, the sinking amounting to more than 9 ins. under the tower, which was thrown out 11⅓ ins. at one place 87 ft. above the ground. The face wall had also settled and inclined irregularly, but not to such an extent as the tower. Trenches or pits about 8 ft. wide and 22 ft. long were opened in front of the tower and wall, and carried down to the bottom of the concrete footing, which is about 13 ft. wide. The pit was sheet-piled and a timber platform built at a suitable level and very carefully made horizontal. A 4-in. auger was then driven horizontally below the footing to determine the form of its lower surface, of which no plans existed. It was found to be irregular, and many of these horizontal soundings had to be made to obtain the desired data. When this work was completed, the pit was excavated still deeper and a second horizontal platform was laid below the first on carefully leveled stringers. When this was finished, 10 x 10-in. piles, 14½ ft. long, were driven horizontally by 30-ton hydraulic jacks in the manner shown in Fig. 10. When a continuous row of these piles had been forced under the entire surface of the concrete footing exposed in the pit, a second continuous row was driven immediately below it. The piles of the first row projected about 18 ins. beyond the concrete footing, and those of the second row projected 18 ins. more, so that the two rows had the effect of widening the foundation of the wall about 3 ft. After this work was finished in one pit it was filled with earth and tamped, and another pit opened immediately adjoining it, the work being continued until the entire front of the wall and tower was underpinned. About five months were spent in the work on the 45-ft. base of the tower and eight months in that on the 380-ft. wall. The operations were intended to arrest the inclining of the wall and were manifestly powerless to straighten it.

The simplicity, economy and perfected directness and efficiency of the author's method is emphasized by comparison with an elaborate system employed by English engineers to arrest the settlement and partially restore the displaced walls of the Yarmouth City Hall. Here forty-four cast-iron cylinders in externally flanged sections were sunk on both sides of about 300 lin. ft. of wall, and a row of longitudinal iron girders was set on top of the cylinders, parallel to the wall, on

Mr. Skinner. each side. Numerous transverse beams 16 ins. deep were then put across the wall under its footing and screwed up to the longitudinal girders at each end by 2-in. suspender rods. Some rectification of the wall was accomplished by adjusting the screws, and a suitable trench having been dug, a new concrete footing was made to enclose the beams and girders and widen the base. The cylinders were 22½ ft. long, 1⅜ ins. thick, and 30, 36, 54 and 60 ins. in diameter, according to the weight of the adjacent wall; all of them were filled with concrete. The work was accomplished in twelve months at a cost of $41 000.

Mr. Bogart. JOHN BOGART, M. Am. Soc. C. E.—A few more words may be added to the author's statement that the contractors were responsible for any damage to adjacent buildings, resulting from their operations. The law requires the owners of a new building to take care of existing adjacent buildings, provided only that the foundations of these buildings are at a certain depth below the curb. Under these circumstances it was deemed proper that the contractors for the foundations of the new building should do whatever might be necessary to take care of the adjacent structures, and they were therefore requested to assume that care and responsibility, including in their tenders a sufficient sum to pay for such service.

The author shows in Fig. 5 a section of the foundation of the Stokes Building, which is so built that the line of pressure of the wall on the concrete is not centered, and consequently produces tension in the base, evidence of which was detected during the progress of the work. This base had its bottom over 2 ft. above the floor of the cellar of the old adjacent building and was founded on sand. The water level was at, or a few inches below, the floor of the cellar of the latter, and nothing kept the sand from running except a small brick wall, part of which was merely the wall of an area.

The experience gained during the progress of the work described in the paper proves that when cylinders are used to support structures of any size where work is to be done immediately adjacent to them, these cylinders should be large enough in interior diameter for reasonably comfortable access, both for working and for careful examination. All the cylinders in the work described were examined frequently during their sinking by an engineer, who went in each instance to the bottom of the cylinder. Borings had been made in adjoining cellars as near to the proposed location of the cylinders as possible, but their indications were misleading. As a matter of fact the original scheme for the foundations of the very heavy Queen's Insurance Building had to be changed on account of discoveries made during the sinking of the cylinders, which showed that the conditions were different from what were apparently indicated by the borings. Another reason making it important for an engineer to be able to examine the work is the fact that the reports of men laboring in such small cylinders under fairly heavy air pressure are not always reliable as to the character of

the ground at the bottom. Solid hard-pan was several times reported, but when an engineer made an examination, his bar went through the hard pan and was nearly lost. In another case when solid rock was reported, it turned out to be a boulder of moderate size which was broken up and taken out, the cylinder afterwards being pushed much farther down. Mr. Bogart.

This method of transferring the weights of structures to rock or other reliable bearing, even when such bearing exists only at a considerable depth, has greatly lessened the difficulties and dangers connected with the erection of heavy buildings adjacent to other structures whose foundations are unsatisfactory and not to be depended upon when deep excavations must be made in their immediate vicinity.

HENRY B. SEAMAN, M. Am. Soc. C. E.—It has been stated that there was evidence of tension in one of the old foundations exposed during the progress of the work. It should be explained of what this evidence consisted, whether it was the presence of cracks, or merely the fact that the line of pressure did not fall within the inner third of the foundation. The latter condition is usually assumed to produce tension, and may be very generally found in retaining walls, but no tension exists, nor can exist, without a tie. So long as the distance from the line of pressure to the near side of foundation is sufficient to withstand one-half the load, without settlement, there will be no tension, nor even cracks, in the foundation. Mr. Seaman.

JOHN F. O'ROURKE, M. Am. Soc. C. E.—The author calls attention to the very heavy weights that can be borne by hard-pan, a fact proved by experiments made while underpinning the walls of a building in New York City in the manner described in the paper. The pipes had a cross-section of about 20 sq. ins., and were provided at the bottom with a reinforcing ring which gave the bottom of the pipe a section of about 50 sq. ins. After the hard-pan was reached, the pipes were cleaned out by means of a water-jet and then subjected to heavy pressure by means of a hydraulic ram. They were somewhat over 40 ft. long, and under the pressure of the ram were shortened about $\frac{1}{4}$ in., springing back to their original position when the pressure was removed. The fact that the top of the pipe returned to its original level showed the compression to be in the metal and not the hard-pan. Mr. O'Rourke.

CHARLES E. EMERY, M. Am. Soc. C. E.—The removal of parts of foundations has been practiced before the work described in the paper, the underpinning of the Washington Monument being an instance, but the latter undertaking was carried on above the level of ground water, and did not present the difficulties inherent to going below water and working in a cramped position. The author's simple and effective methods are very different from those in vogue only a few years ago. When the New York Steam Company's building was erected by the speaker, he could not obtain permission to pile, and was forced to rest the structure on sand. One side of the company's building was on Mr. Emery.

Mr. Emery. good sand, and the foundations presented few difficulties. On the other side the sand was fine and moved easily when wet. At such points the company bought the abutting property with the exception of one building, which had been secured by a speculator and an exorbitant sum charged for it. The tenant of the basement was persuaded, however, to allow work to proceed on his part of the premises, and a suitable foundation was finally built, which carried both buildings. The excavation was extended without pumping a few feet below the water line, and the concrete was deposited under water very carefully. Since gaining that experience, the speaker has had considerable faith in a good concrete foundation well down into the sand, for, although this building settled somewhat, a few vertical cracks near the tops of the walls relieved the inequality of the strains, and no further settlement took place. In one of the large office buildings which was being constructed at the same time on a pile foundation in similar material a number of the main columns sank, carrying the piles down with them, and it became necessary to relieve the load and put in extra columns and inverts to distribute the weights over a larger number of piles.

The pressure per square foot on the sand foundation which sank was approximately $3\frac{1}{2}$ tons per square foot. An attempt was made to reduce the load to 3 tons per square foot, but it was impracticable to rack out sufficiently to accomplish it. The final weights were to have been 4.4 tons per square foot under the columns, 4.25 tons per square foot under the chimney, and 4.2 tons under the side walls, but the building has never been carried to its full height, so that the actual loads do not exceed $3\frac{1}{2}$ tons per square foot at the locations stated. The calculated pressure on the soil under the front wall was only 3 tons, which was rather a disadvantage than otherwise, as that did not sink as much as the other walls and caused a crack through the central arches. H. W. Brinckerhoff, M. Am. Soc. C. E., who was in immediate charge of the work, thinks that if the inverts at some openings in the front had been left out, the settlement would have been pretty nearly uniform.

In erecting a power station at Fifty-eighth Street and Madison Avenue, in New York City, it was necessary to build the structure on the site of an old watercourse known to be filled with quicksand and mud overlaid by 14 to 16 ft. fill of good earth well compacted after a series of years. The building was a temporary one, so the fill was partly excavated and the building founded on the remaining solid earth at a depth of about 10 ft. below the curb, the base of the chimney being carried lower and supported on piles driven as close as possible. The building has four stories and a basement, and although but 5 or 6 ft. of filled material separates it from the mud and quicksand, it has never required bracing, and a crack developed at one rear corner only, which relieved the strain due to a want of uniformity in settling. The chimney has not moved and the station is in good order.

CORRESPONDENCE.

ALFRED NOBLE, M. Am. Soc. C. E.—The writer's connection with the work described in the paper was at first as consulting engineer to advise as to the method of supporting buildings proposed by the author and to outline the detail plans, and afterward as superintending engineer to see the work carried out. The method appearing perfectly feasible, the next question was as to the size of the supporting columns and the manner of securing a proper foundation for them. It was supposed that bed-rock would be found about 35 ft. below the foundations of the adjoining buildings with the probability of a thin layer of overlying hard-pan. There was good reason to suppose that the surface of the rock would be quite uneven. Mr. Noble.

It was at once recognized that where heavy weights were to be carried, facilities must be given for laying bare and leveling the surface of the bed-rock so that a fair, square bearing could be secured for the column. This necessitated the use of compressed air in preparing the foundation, and fixed the minimum inside diameter of the column as that in which a man could work; for the Western Union and Stock Exchange Buildings this was taken 28 ins., giving, with a thickness of 1 in. of metal, an exterior diameter of 30 ins. It was inconvenient to work in so small a cylinder under compressed air, and progress was slow; but the use of compressed air was generally unnecessary until hard-pan was actually reached, it being found practicable to remove nearly all of the quicksand by working a jet continuously while jacking down the cylinders, the quicksand passing off with the overflow.

After pushing the cylinder down to its final bearing on the leveled surface of the rock, a man was again sent inside, and drove steel wedges under the cutting edge wherever possible. As this, however, was far from being a continuous metal bearing, and as, furthermore, it was really a bearing on rock, on an annulus not more than 2 or 3 ins. wide, it was thought proper to limit the unit strain in the cast-iron cylinders to about 5 000 lbs. per square inch. A further consideration to the same end was the fact that during the subsequent sinking of the caissons alongside, the support against flexure afforded by the surrounding quicksand would be somewhat disturbed.

The concrete with which the cylinders were filled was made with a rich Portland cement mortar; at least the first 6 ft. was filled under compressed air. No account was taken of the concrete filling in calculating the strength of the columns. There is no doubt, however, that it added considerably to their strength at the time the caissons were sunk alongside, because during the intervening days (or weeks in some cases), the concrete would have attained much hardness, and by means of the interior flanges of the cylinders a considerable portion of

Mr. Noble. the load would be transferred through it to the bed-rock on the interior of the cylinders. This transfer would be facilitated by a slight yielding of the packing at the joints of the cylinders and of the wedges at the cutting edge.

In the case of the old four-story and basement building, No. 24 New Street, the weight which each column would have to carry was less than could be imposed by the hydraulic jack used in forcing it down. It was, therefore, believed that a series of 10-in. pipes having the necessary section of metal would afford adequate support if sunk by the jack to refusal on the underlying hard-pan. An experimental column showed that the hard-pan was impenetrable under the maximum pressure given by the jack, and the plan was carried out on this basis. The decision as to size of columns in the two cases was made at one and the same time, and the results proved it to be correct.

There was no settlement in the buildings which could not be accounted for by the compression of the material in the columns themselves, and in each case was quite insignificant compared with the usual settlements in buildings founded on earth.

The wall of the Stokes Building has, as the author states, a spread foundation. The surface of ground water is about 2 ft. below it, so that the foundation rests directly upon material which is not quick. This was not important, however, because the excavation in the neighboring lot for the new Queen's Insurance Building was to be carried into the quicksand, and the foundation would surely be weakened.

The cross-section of the lower part of this wall, Fig. 5, shows a remarkable instance of a spread foundation on which the load is not central. The arrangement is obviously one which should produce tension in the vertical face: during the work of sinking the supporting cylinders, conclusive proof was afforded that this existed.

The method described in the paper is particularly applicable where a material capable of supporting a great weight can be reached readily by the use of compressed air. It must be noted that it cannot be carried out without a temporary weakening of the original foundation, a portion of which must be removed. In quicksand the bearing capacity of a neighboring portion will inevitably be somewhat reduced and a little carelessness, permitting an inrush of sand into the cylinder, may cause serious results; but with due care the method is entirely practicable, is economical and should find extended application.

Mr Schenck. A. A. SCHENCK, M. Am. Soc. C. E.—The author speaks of the necessity of carrying on operations in compressed air in sinking foundation cylinders. This method has been considered necessary in many cases of cylinder settlement, and, of course, in this case those in charge are the best judges. In nearly all cases of cylinder settlement, either the pneumatic process or the plan of pumping out the cylinder in some way appears to be considered necessary for the pur-

pose of excavating or removing obstructions, preparing the bottom, placing concrete, etc. Both the use of compressed air and the use of the pump have disadvantages connected with them besides the expense. Where the material to be removed from the cylinder requires more than mechanical appliances working under water, it will be found both cheaper and better to send down a man in the diving suit much more frequently and generally than is now done, in place of pumping out. Mr. Schenck.

About ten years ago the writer had occasion to sink cylinders 8 ft. in diameter, for piers of a bridge across a western stream. It was impossible to drive piles to a safe depth. By sinking cylinders and excavating within them, it was possible to force the piles to a satisfactory depth. A very much smaller number of piles was required, and solidity and resistance to drift were secured without the expense of solid masonry piers, stone for building purposes being hard to obtain.

The assistant engineer in charge of test borings reported only fine sand to the depth to which it was intended to sink the cylinders. The piers were located on low sand islands or bars, the surface of which was about a foot above extreme low water. An 8-in. centrifugal pump was placed on the sand bar, and used during the earlier part of the work on each cylinder, the material being removed by buckets. As the depth increased, it was found that the pump sucked the finer material from around the cylinder to such a distance that the inflow of water became very rapid. Below a depth of a few feet, also, the material changed to compact gravel with small boulders from 1 to 2 cu. ft. in size, which required hand labor in the cylinders. The latter part of the work was therefore carried on with the diving suit. No professional diver was employed. A diving suit and apparatus were rented, and ordinary laborers sent down. They were allowed higher wages for such work with short hours. There was no trouble in getting plenty of men who would go down under such simple conditions and for moderate depths. The buckets were filled by hand. The shells were sunk until they were considered to be below any scouring action of the river; but the settlement could have been carried much lower without difficulty, had there been anything to justify the expenditure of more time and money. Below the bottom of the cylinders, piles were then driven, not only increasing the safety against scouring, but securing stability by a foundation firmly and deeply rooted in the hard material. The outer circle of piles was driven first.

No attempt was made to cut off the piles and cap them before filling the cylinders with concrete. It was considered that better results would be secured without this. Since the pile tops rise to varying distances in the concrete, there is no horizontal line of cleavage at

Mr. Schenck. which the mass of concrete can tilt on the piles. The concrete mass grips the piles securely, making one rigid column from the bottom of the piles to the top of the concrete; and the stability of the piles in the ground is extended to the whole column.

The concrete was deposited in the water in the column at first by spouting it; but in parts of two cylinders it was thrown into the water as mixed, the water being about 10 ft. deep. Although this method is in violent contradiction of most theories, the results appeared to be fully as good, if not better, than those of usual methods. In fact, it is believed that the concrete so placed was better, and better distributed, and more compactly placed, than any other. The cement, sand and stone appeared to go to the bottom at once in one mass, and as well mixed as when first prepared, and the concrete to diffuse itself much better. The water through which it passed retained very little of the cement. The resultant mass was apparently more homogeneous and solid than if placed in air and rammed.

The river is in a densely wooded country, and carries much drift during floods, including many trees 5 or 6 ft. in diameter, and over 100 ft. in length. Occasionally such trees have broken against the cylinders without tilting or injuring one of them. No settlement of bearings or of the concrete occurred in the cylinders after the filling with concrete was finished.

The shells were of ¼-in. plate, in two pieces to the circumference, about 4 ft. high, lap joints, all rivets being ¾ in. and spaced 3 ins. The plates were bent to the circle before shipment. All riveting was done on the ground. At first the shells were settled by weighting, but tapping with a pile-driver hammer was afterwards cautiously attempted. It was found that with the riveting stated, it was safe to give a blow of 3 ft. fall of hammer weighing 1 800 lbs., taking care not to continue the blows long after the movement downward had ceased. Two layers of 12 x 12-in. timber, crossed, were laid on top of the unflanged shell. This mode of settling disturbs the surrounding material less than the water-jet. The full lateral stability and frictional effect of the surrounding material is retained. By not pumping out, heavy stresses upon the shell are avoided, and the hundred and one difficulties which come from inviting pressures.

In soft mud, it would be necessary to excavate in the shell some distance below the proposed level of the tops of the piles, to keep the mud from being forced upward during the driving and covering the pile heads. A few minutes' work of a diver will ensure the cleanliness of the pile heads. The placing of concrete should be done slowly at first, so that the cement between piles is given time to settle to a stable bearing and reasonable depth. If the mud itself will not permanently sustain concrete, it will be found that by adhesion to the piles, the concrete will generally come to rest. Where the depth of

mud is too great to allow one length of pile to reach hard bottom, it is possible to go part way with a cylinder, excavate, and then drive single lengths of piles, using a temporary follower. After the shell has been well filled with piles, it will be found that the mud will come into the shell much more slowly; and the piles can be kept clear of it long enough to permit the concrete to be placed on the pile heads. The retention of the water in the shell at all times will tend to keep out the mud. The shell may be of cheap construction where no pressures are created by pumping out. The iron shell may even have a wooden lining to serve as a mold for the concrete, the iron being removed and used again, and iron protection being left only at heights where protection from erosion is necessary. This method of not pumping out depends on the engineer's willingness to let the concrete do its own capping, leveling and fitting upon the piles. The

Mr. Schenck.

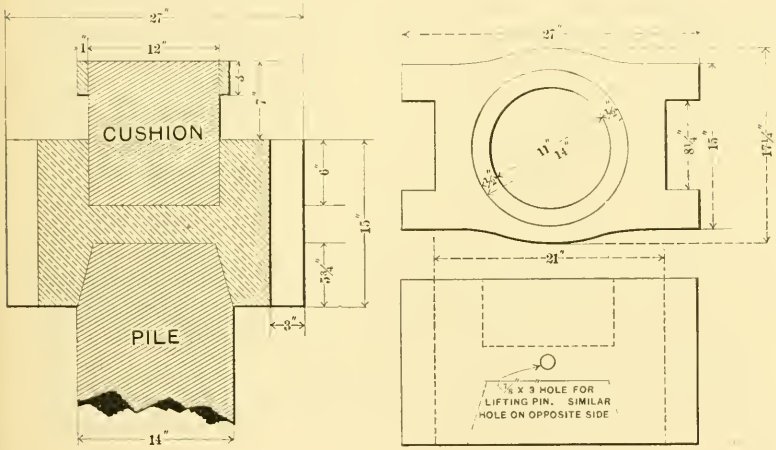


FIG. 11.

results of the trial of this method at the structure named are given to aid the constructor in deciding this determining question. If concrete will so dispose itself as to do away with pumping or pneumatic work in any case, the saving of time, expense and difficulties is evident. So far as permanent strength is concerned, the clear span between piles is so small, the bearing power of a beam of concrete of such depth is so great, that the strength would seem to be beyond question.

It is well to note in this connection that it is often a loss rather than a gain to penetrate through a compact layer of material in order to reach solid rock. If the rock be uneven, this layer acts as a natural concrete deposit to distribute the weight, and its frictional hold of the rock is very valuable. It is often better to enlarge the area of the

Mr. Schenck. proposed cylinder to suit such material than to go down in search of a sloping rock, with the expensive leveling that will be necessary when the shell reaches it.

Where there is no underlying material that can be penetrated by the piles, so as to secure vertical stability to the piles in very soft mud, some other system must be used that will give stability against tilting.

It is desirable that where piles are loaded with concrete without cutting off, the pile heads should be uninjured to any great extent. The writer therefore submits a design of cast-iron follower and cushion which has been in use on the New York Central and Hudson River Railroad some years, under direction of Mr. W. D. Otis, General Road-master. This device, Fig. 11, not only enables piles to be driven into hard material otherwise impenetrable, but at the same time preserves the pile head perfect. The pile heads are dressed to fit the follower. The writer has seen large groups of piles driven into hard-pan, yet the heads of the whole group were left as perfect as if they had been turned.

The cylinder type of substructure is full of advantages, and has come to stay. At present it is tied too fast to the older and more expensive methods. It is a development of the old Cushing pier, which was not much more than a protective belt placed around a group of piles.

Mr. Thomson. T. Kennard Thomson, M. Am. Soc. C. E.—Having carefully watched the underpinning of the buildings mentioned by the author, and seen how successfully his method works, the writer thinks he has not sufficiently emphasized the difference between this and other arrangements for supporting a wall. This system gives a permanent and safe foundation, while the others act more as falseworks, which may or may not be safe while in use, and may or may not be safely removed, especially if there is quicksand underneath, without affecting the adjoining buildings.

The author has illustrated two distinct systems of working; first, the pipe system, which can only be used under favorable conditions; and, second, a system of large cylinders, which can be used anywhere.

The first consists of a pipe pile or column, in which the diameter is too small to permit an observation of the bottom, and the pipe is driven to refusal, or until the pressure exerted by the jack is greater than the subsequent load to be carried by that individual pipe.

Of course, an electric light and mirror or camera could be used, but this would be of little value, as a small boulder might be mistaken for bed-rock. The pipes are generally made strong enough when empty to carry the load, and are then filled with concrete, which, although adding greatly to the strength, is not depended upon. When made of steel, there is, of course, no effectual way of preventing ulti-

mate destruction by rust, while the objection to cast iron is that it is liable to breakage under the jack. A thin steel pipe could be forced down, and a cast-iron column afterwards placed inside of it, having the intervening space filled with concrete or grout, which would make a cheap and permanent foundation. Mr. Thomson.

When the question of underpinning the old building at No. 24 New Street came up, the author suggested the pipe scheme. As doubt was expressed as to its feasibility, a gas-pipe driver was designed and built, and a 2-in. gas pipe was driven down with the aid of a water-jet, where the first support was proposed. This boring indicated that there was nothing but quicksand, clay and sand between the surface and hard-pan. The absence of boulders was what had been hoped for, because these pipes can only be depended upon when they are driven to hard-pan or rock; for while the resistance to the jack might indicate that there would never be enough pressure from the walls to cause further penetration, still, if the pipe were stopped on a boulder under which lay quicksand, the sinking of pneumatic caissons nearby might draw the material from under the boulder and allow the wall to settle. A preliminary boring of this nature should be made for each individual pipe that is to be used. The subsoil of a greater portion of lower New York is similar to what was found at the new Commercial Cable Building, which is an ideal location for this kind of underpinning.

The borings mentioned having removed all doubts, it was calculated that a 10-in. pipe of $\frac{3}{8}$-in. metal, weighing 40 lbs. per foot, would be strong enough for a temporary support. A number of these were obtained in the market at once, in lengths of about 5 ft., with butt joints and outside couplings. A smooth outside joint would have been preferred, but could not be obtained so readily. It was supposed that there might be some difficulty in dislodging the material under the pipe, so a cast-iron shoe or cutting edge was designed, having connections for three $\frac{3}{4}$-in. gas pipes, and a system of holes to distribute the water from the $\frac{3}{4}$-in. feed pipes all around the cutting edge. The first 10-in. pipe had one of these shoes, which worked well, but it was found that a single gas pipe dropped from the top and connected with a hose was ample, so the expensive shoe and three fixed gas pipes were dispensed with in the rest of the 10-in. pipes, which had the cutting edge stiffened by an ordinary coupling. It was also found convenient to have a temporary short section of pipe, about 3 ft. long, screwed on top of each permanent section as it was being forced down. This short section had three vertical slots, about 3 ins. wide and $1\frac{1}{2}$ ft. long, to permit the gas pipe and hose to be worked up and down without disturbing the jack. A connection was made lower down for the overflow. The quicksand passing through the overflow pipe was so fine that it looked like mere dirty water until allowed to settle. An architect on another building who tried to pump water from under

Mr. Thomson. his foundations thought he was only raising dirty water, but after pumping twenty-four hours or so, without lowering his water level to any extent, he stopped, and subsequently had a cave-in.

The following is the writer's report to the contractors on the sinking of the first 10-in. pipe at No. 24 New Street:

"The first cylinder of the ten proposed to support the old wall (nine were used) has six sections of 5 ft., and one of 4 ft., $\frac{3}{8}$-in. metal, having 12 sq. ins. section, and weighing 40 lbs. per foot, with patent couplings on the outside and butt joints. On the bottom there was a cast-iron shoe $1\frac{1}{4}$ ins. thick, with small holes for jetting connected with three $\frac{3}{4}$-in. gas pipes to supply the water with.

"A hole was dug in the ground about 3 ft. deep, and two 5-ft. sections placed in position under the jack, at 10.56 A.M., Saturday, March 28th. In three minutes the pipes had been driven 8 ins. Numerous stops were made to plumb the pipe, which at 12.11 P.M. had been driven 2 ft. 6 ins.; by this time whenever the jack was in use, the pressure was taken off by the two pine shores which braced the 12-in. beams. The old wall was so rotten that there was no support for these temporary 4 ft. I-beams, and it was considered unsafe to cut 4 ft. out of the wall without temporary wooden shores. On filling the pipe with water again, it escaped under the shoe.

"The third length, 5 ft., was added at 2.15 P.M., and the pipes disconnected with the shoe, after which the pipe was kept filled with water by shoving a pipe down from the top. The overflow was heavily laden with quicksand. The pipe was driven about 11 ins. between each shift of the jack in from six to ten minutes, all the way down to hard-pan.

"The fourth length was screwed on at 4.09 P.M., and driven home at 5 P.M., when work stopped for Sunday.

"Monday, March 30th, work started at 7 A.M., and the fifth length was down at 8.55 A.M. The sixth and seventh lengths were under water at 11.20 A.M. By this time every application of the jack lifted the beams off of both shores. The jack was removed, and the sand jumped out of the pipe, after which the jack was again put in place and worked to its full capacity, 60 tons, without further sinking. The previous 2-in. boring showed 34 ft., and 34 ft. of 10-in. pipe having been driven with the above results, the presumption was that rock or hard-pan had been reached. The caissons afterwards sunk besides these pipes proved that they were resting on hard-pan. When the men got accustomed to the work, the remainder of the pipes were put down from 33 to 35 ft. in five or six hours."

In this building there was no difficulty in removing the old foundation wall to insert the pipes, jacks, etc., because the original mortar was not much better than powder.

In order to increase the strength of some of the 10-in. pipes, 8-in. pipes were placed inside after sinking, concreted and grouted.

The second system has cylinders of large enough diameter to permit a man entering, and, if necessary, blasting out boulders until bed-rock is reached. These cylinders under the Western Union Building were 30 ins. in diameter outside, and were forced to hard-pan by two jacks and a water-jet when the jacks were removed, a small air lock

being put in their place to permit a man to enter and excavate the hard-pan. Sometimes the jacks would be replaced, and the cylinder forced down farther. Mr. Thomson.

The writer certainly does not wish to be understood as recommending for use near any heavy building any kind of a coffer-dam which is pumped dry without a compressed air chamber. So far these pneumatic caissons have only been forced down to hard-pan or rock by means of a hydraulic jack under old buildings, the weight of whose walls give sufficient resistance to the jacks; but by arranging a system of heavy movable weights, the same system might be used to advantage for new foundations, and it would seem that something of the kind is wanted where the cost of ordinary pneumatic caissons is prohibitive.

Under the present New York building laws, if pneumatic foundations are used, and the foundations carried to rock, the pressure exerted on bed-rock must not exceed 30 000 lbs. per square foot, or 25 000 lbs. on good concrete. Now this often requires such a large cylinder that the expense prevents the owner from attempting to go to rock at all, and he decides on a pile foundation instead, which is certainly cheap, as he is allowed to load each pile with 40 000 lbs., and place them as close together as he can. In fact one of the highest buildings in New York is being founded on piles, which are so close together that they are practically in contact, and when cut off, cannot be much more than 10 ft. long. Moreover a whole bunch of these piles is most decidedly out of plumb. Would it not be very much better to leave the piles out entirely, and put the money in a good thick bed of concrete over a larger surface, or better still, have a non-corrosible column carried down to bed-rock, even if the pressure on good rock was 80 000 to 100 000 lbs. per square foot, instead of putting 40 000 lbs. on a 5-in. pile?

Mr. Schenck advocates divers instead of compressed air, but he must have been exceptionally fortunate in his selection of divers. Work in compressed air is generally under the supervision of an engineer, which is certainly a more reliable plan than to rely on the word of an ordinary diver. The writer has met one diver whose word he could trust, and that man would recommend compressed air every time a good piece of work was desired.

There was a bridge where the coffer-dams leaked so badly that it was decided to dump 5 ft. of concrete over the entire bottom. The divers were paid $40 a day to look after this, but as the coffer-dams continued to leak and the divers reported the surface of the concrete dead level, it was decided to start the masonry on a timber platform and gradually sink it until it rested on the dead level concrete. The Chief Engineer, however, thought he would have a look at the concrete first, so he rigged up several more pumps, and by hard work

Mr. Thomson. managed to lower the water long enough to examine the concrete, which proved to be anything but level, in fact there was one hole about 5 ft. wide by 20 ft. long and from 4 to 5 ft. deep. The coffer-dams were eventually made water-tight and all the concrete blasted out.

Mr. Saunders. W. L. SAUNDERS, M. Am. Soc. C. E.—It may perhaps interest some members to know what kind of a machine is that which is shown in Plate I. It is, perhaps, but an incident in connection with this important work to know by what means the cutting away of the wall was accomplished. The author used for this purpose a gadder, the upper part of which is shown in the illustration, a machine about which, perhaps, little is known except by those members who may be familiar with marble quarrying.

It will generally be admitted that the author has described a very substantial method of underpinning. It is in no sense a cheap method, and anything which aids in reducing the cost of such work is worthy of notice. To cut away old brick masonry, especially that laid in cement, is usually a slow and expensive operation. By means of this gadder the author outlined the space which he wished to cut away by a series of holes driven in a manner which is illustrated by the perforations separating postage stamps. The rock drill is mounted upon a special frame which consists mainly of a cast-iron base carried on four wheels, to the end of which is pivoted or hinged a standard or post. This standard carries the rock drill through a carriage which moves upon parallel guides and by means of which the drill is raised or lowered to any desired position. The standard is capable of a varied adjustment from a vertical position to one very much inclined. By means of this adjustment, together with the movement of the drill through the carriage on the standard, a line of holes may be inserted in any position or at any angle against a wall. The frame is so designed that it is stiff enough to resist the thrusts of the drill while working even near the top of the post, Compressed air, which is always available in a work of this kind, furnishes the power to run the drill and the holes are driven with great rapidity. Once the wall is thoroughly perforated it is an easy matter to break away the intervening masonry.

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No. 800.

EXPERIMENTS WITH A NEW METHOD OF HEATING AND VENTILATION.

By Charles Carroll Gilman, F. Am. Soc. C. E.

Presented November 18th, 1896.

The principle of the method of heating and ventilation discussed in this paper is the utilization of the fact that air rarefied by heating will cause a circulation in the rooms of a building. This principle is applied practically by cooling the air near the ceiling of a room, by heating the air near the floor, or by both means. It has been the belief of the author for some time past that the mechanical condition for such a system of heating might be furnished by the use of "earthenware-house" construction in the floors and ceilings, and to test the validity of this belief he carried out the two sets of experiments described hereafter.

The first set of experiments was carried out in the kitchen of the author's village homestead, which was then vacated for repairs. It has a water-backed cook stove piped for domestic uses, to waste in the bathroom on the floor above, and is supplied by a tank in the attic.

The stove was taken out and set in the cellar below, and the flooring and ceiling coverings were ripped out. Porous brickstuff planks, 1½ ins. thick, were then fitted and spiked on the exposed faces of the floor joists, in order to furnish an air-tight and fire-proof foundation. This floor measured 12 x 16 ft., and served as a support for a heating coil composed of lengths of 1¼-in. iron pipe laid 12 ins. apart, and suitably connected with the water-back of the stove on the floor below. This coil was tested for leakage and provided with a petcock to enable air to escape, and the whole floor was then covered with a 4-in. layer of concrete made of equal volumes of native hydraulic lime, sand and small gravel, as shown in Fig. 1.

For the purposes of the experiment a temporary ventilating ceiling was made by sheathing the under surfaces of the rafters with ¾-in. matched pine boards. This ceiling was perforated with 144 auger holes from 4 ins. to 6 ins. apart. One-third of these were 1 in. in diameter and the remainder ⅝ in. Five of the 1-in. holes were provided with tin tubes opening in the floor of the bathroom, and the remainder opened into the wall void, 10 ins. in depth, having direct communication with the outside air.

About three months later, the floor had hardened and the experiment was begun. A platform was put up near the ceiling, the auger holes were corked from below, and blankets were hung over the inside of the doors as an additional precaution against the entrance of the air. A thermometer was affixed to a partition wall at the floor level, another at an elevation of 6 ft. and a third at the ceiling. A fire was then started in the stove and maintained for three hours, when the kitchen was entered. Each of the three thermometers indicated a temperature of 72°, the water in the floor coil was at 135° and the temperature outside the house was 40 degrees.

To rid the room of humidity, the corks were drawn, which was followed at once by a drop of 4° in the reading of the middle thermometer, the others remaining at their former reading. It was found that all the larger orifices, except the five opening into the bathroom, were discharging air downward, while no movement was discernible at the mouths of the smaller ones. The five tubes leading to the bathroom were discharging air upward under a pronounced pressure, although not of a volume equal to that dropped into the room through 43 holes of the same size. The only explanation of this state

of affairs is that the outside air at 40° entering through 43 1-in. holes was pushing up, because of its greater weight, the rarefied air at 72° through 96 $\frac{5}{8}$-in. holes and the five 1-in. holes leading to the bath-room.

Subsequently the floor of the adjoining room, measuring 16 x 18 ft., was provided with a similar coil, and the experiment repeated with the same results, except that six hours instead of three were required to bring the water to the same temperature.

Fig. 1

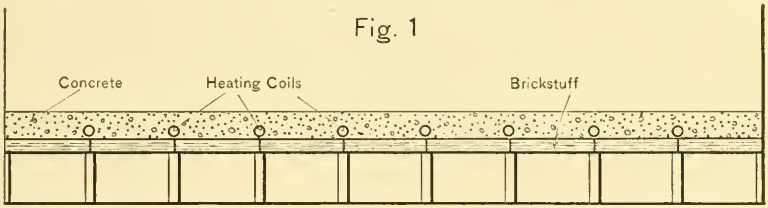
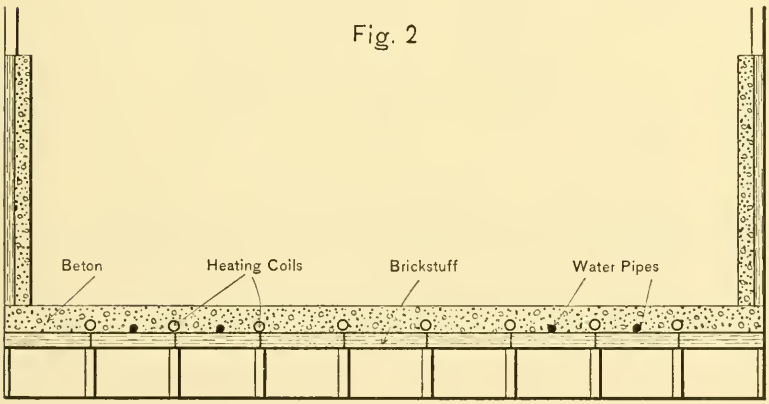


Fig. 2



These experiments show that under the given conditions there is an exchange of hot and cold air at the ceiling, which prevents draughts, and it is practicable to warm a small cottage with kitchen, living room and two bedrooms, having about 500 sq. ft. of floor area, by means of water from the cook-stove.

The second series of experiments was carried out in a small green-house annexed to a steam-heated dwelling. The greenhouse was a frame structure measuring 10 x 20 ft. in the clear, and 14 ft. high above the floor. The walls were sheathed to a height of 4½ ft. with brick-

stuff, the remaining distance and the roof being of glass, single sashed but double glazed. The floor was prepared somewhat like that of the kitchen already described, and contained in addition to the heating coil several water pipes, as shown in Fig. 2. The floor was made by soaking brickstuff planks in water before laying them, and using as a covering a mixture of one part of Portland cement to four parts of clean, sharp sand, screened through a No. 6 sieve. The concrete previously employed was not used on account of its deficiency as regards the conduction of heat. The greenhouse has four ventilating transoms beneath the eaves, a small door leading to an open porch and four large folding doors, which, when thrown back, make the greenhouse and adjoining music room practically one large room. The floor coils were supplied with steam from the boiler in the house. The entire cost of the new outfit complete was about $2 per square foot of floor area.

Sixty days after the completion of the work steam at 7 lbs. pressure was turned on. The outside air was at 29° at the time and the air in the annex at about 65 degrees. It was found by means of smoke tests that the currents of air were rising from the floor to within several inches of the roof, where they spread out horizontally to the walls and sank to the floor. The only ventilation was through a small crevice between the roof and its supporting wall plate, and under the door leading to the porch. The transoms were not used until spring. The mean temperature maintained was 75° during the day and 60° at night, although several times when the outside air was 18° to 22° below zero, the temperature in the greenhouse sank to 52° in the early morning. The furnace fire was banked from 10 P. M. to 6 A. M., the greenhouse being warmed during the interval by the heat stored in the floor. Roses, chrysanthemums, carnations and other plants bloomed freely in their respective seasons, and bulbs, cuttings and seeds were started successfully in the spring.

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No. 801.

CAR TRACKS AND PAVEMENTS.

By JAMES OWEN, M. Am. Soc. C. E.

PRESENTED DECEMBER 16TH, 1896.

WITH DISCUSSION.*

The present enormous development of transit facilities in the streets of urban and suburban communities, and the desire for immediate results rather than for permanent construction, have already led to complications and problems which demand the careful study of the engineering profession, and to which more particular attention in the future will have to be given.

In the construction and maintenance of streets and highways, certain principles and practices have been formulated, and by selection accepted as giving the best results, economically, for the particular travel they have to endure. In the maintenance of railroad tracks, the practice has been more crystallized, and a standard has been adopted from which only the lack of means excuses a departure.

These practices exercised separately offer no field of discussion, but as soon as the maintenance of track and that of pavement are united

* The discussion on Papers Nos. 801 and 802 was a joint one, and will be found on pages 78 to 132.

in one street or in one city, then the relations of the two interests become complex, and the economic adjustment of the differences between the parties interested opens up a wide field of discussion, in what may be called, at present, at least, an undeveloped territory, and in which, therefore, it may not be considered improper to inject a few suggestions.

The first point to be considered is the relation of the owner of the railway to the authorities in charge of the highway, and involves so far three situations :

First.—Where the municipality owns both track and street.

Second.—Where the company operating the railroad assumes as part of its franchise the care of the pavement in the street.

Third.—Where the municipality cares for the pavement outside the tracks, and the company cares for the track and the pavement between the rails.

While the first two conditions actually exist, they are so rare in this country that much consideration cannot be given to them, except as to formulate what, in some minds, might be called the ideal. They have only been adopted in isolated cases, under peculiar conditions, and do not seem to commend themselves generally to municipalities or capitalists.

It will not be out of order, however, to allude to two or three ideas that suggest themselves on these two heads. It would be of undoubted advantage to have the control of track and pavement vested in one authority, as more economic results can be obtained, and the riding public and driving public would both be placed on a fairly equal basis; but the general unsatisfactory administration of municipal affairs at this time places a great barrier against municipal control. On the other hand when the railroad company assumes control of the whole pavement of the street, the company, as a money-making institution, would not have as high an idea of the character of a good pavement as the critical taxpayers would demand, and when repairs are numerous and costly, they may not be made with the alacrity that a high citizenship would suggest.

Another condition of things might exist where the municipality keeps the whole pavement in repair, and collects from the company the cost of the latter's part between the tracks. This might work satisfactorily if one point did not come up to create trouble ; it is the

one point that is going to make endless friction and is the unconsidered element, viz., the repairing and renewing of the track itself.

Assuming, then, that the existing condition, and for a while the future condition, is the separation of the control of the pavement from the control of the track, it will be in order to consider the relations thereto in a purely engineering sense, and from this consideration certain governing principles which may be of benefit to both parties concerned. As a basis for these relations it will be proper also to assume that the workmanship of both pavement and track are perfect, considering that any departure from this standard of perfection would only aggravate the difficulties.

The construction and operation of a horse railroad on a street or highway, while to a certain extent separating the vehicular travel from the track itself to the area left on either side or between the rails, does not by any means isolate it; it is a matter of history that rails were especially designed to keep the wagon travel away from the car tracks, and it may be fairly assumed that the car travel was a component part of the general travel. With the introduction, however, of a higher rate of speed, either by cable or electricity, the result has been, first, to increase enormously the travel on the cars, so much so that in many cities the main car lines have practically driven away the wheel travel, and, second, the wheel travel has been forced into the two driveways and only in an emergency is the car track space used.

The result to the pavements on the streets is that the travel on them is localized into two narrow lines on which the wear is peculiarly excessive, leaving the space between the tracks rarely used. To compensate this to a certain extent is the fact that rapid surface street transit has decreased to a large extent horse travel, and also has driven a portion of the said travel on to other streets. The effect of this localization of travel on parallel lines to the track is to induce excessive wear in certain spots, and but little in others. The sequence to this, of course, is more frequent renewals in pavements, to preserve uniformity.

It is not in the scope of these remarks to allude to the merits and demerits of any particular pavement; but, to appreciate the situation properly, the accepted standard pavements now in use should be stated, and they are granite block, asphalt, brick, telford and macadam. The various cities in the country have or are making experimental de-

partures into other classes, but the list given above can be considered unchallenged. Of the pavements mentioned, the accepted practice is to lay the first three on a bed of concrete, and in many cases this concrete is continued between the tracks, and in it the ties are imbedded. In the telford and macadam streets, the spaces between the tracks are paved with block, with an edging of block outside the rails to keep the broken stone surfacing away from the rails.

Into these pavements are injected the car tracks, with, as a rule, small ties laid far apart on the bare ground, with a heavy girder rail spiked to them, and tie-rods every few feet. On track of this character loads are carried practically equal to those on steam railroads. The practice of maintenance of track on steam railroads is so matured that allusion to it here would be superfluous, but it is safe to say that every salient requirement of steam railroad track work, except the rails themselves, has been carefully ignored in street railroad track. This is due, as far as the author's observation goes, to these causes—extreme haste in the construction of the work, lack of appreciation of the future use and requirements of the road, and, probably, to lack of funds also.

This situation is, then, to be faced—a carefully laid pavement, designed with one object particularly, viz., permanency; intermingled with it is a perishable construction requiring repairs, incessant and immediate. A prominent street railroad superintendent is credited with the statement that every street railroad track will on an average have to be renewed every ten years. While this statement may be criticized, there is good reason to believe in its accuracy.

Assuming for argument that the ten-year period is correct, the fact that every square yard of pavement within the limits of the track and also to the outer edge of the tie will have to be torn up and relaid every ten years opens up a field of speculation as to the proper practice to be adopted, both for tracks and pavement, in the future, to preserve an ideal in both cases.

Taking the case of a block pavement laid on a concrete bed, with every tie imbedded in the concrete, the actual cost of removing the material is a large item. Relaying is costly, and will sufficient care and watchfulness be given to insure a homogeneous structure afterward? Experience is apt to point otherwise. If concrete is not used between the tracks, the pavement itself will not be permanent and will

require continuous repairs to keep it up to standard, and this standard will be achieved only with great difficulty. This same argument will apply both to asphalt and brick. In the last year, more attention has been given to this question of permanency in tracks, and the use of 60-ft. rails and welded joints is to be greatly commended; but a track spiked to wooden ties laid on soft earth can never be deemed permanent, and the adoption of a track laid in concrete itself is a matter to be considered carefully. There have been for years earnest advocates of this method, and patents have been granted for such practice; but, so far, it has never commended itself strongly to that branch of the profession. It can be readily seen that rails with welded joints, firmly laid in concrete, and superimposed on this a pavement also laid in concrete, would be the desideratum, provided it can be proved that such construction of itself is inherently correct.

The substitution of steel ties for wood, laid in concrete, also suggests itself, and it would be futile to go into the region of speculation; but it is proper to insist, that a practically permanent track is to be desired, on the part of the public, for the good condition of the pavements. It must be also desired by the operating company on the score of economy; and, with a common end in view, it is natural to assume that before long both parties interested will work together.

The foregoing remarks apply to streets of cities, where there is a systematic practice of having good pavements, and with a corresponding desire to keep them so. In others, where there is indifference and even negligence on the subject, the railroad companies, as a business operation, will keep their tracks in fair condition, but the streets themselves will become practically useless for traveling.

In the relation of pavements to tracks in suburban and rural sections, the problem encountered is different in character, but none the less complex, and as the future of electric propulsion will be largely in that direction, a few ideas on that question will not be amiss.

The elimination of the idea of permanency as demanded for city work will first occur. No country highway, whether of earth, gravel, macadam or telford, is designed to give a permanent surface. The theory of use demands constant and incessant renewals in the surface, and breaking up and relaying the pavements themselves need not inflict permanent injury to them. So both track and roadway can be considered purely in their economic view.

If the present practice of wooden ties be found to be the most economical, let them be laid so, even if track surfacing be constantly necessary. The only point to be insisted on is that whatever road material is taken up should be carefully relaid and cared for afterward, to obviate settlement and unevenness.

In laying tracks on suburban and country highways, a few ideas which suggest themselves may be noted. The original tracks for horse cars were paved, as a rule, with cobble stones. Theoretically, it gave a better footing for the horses. On the substitution of electric tracks, the original cobble stones were relaid without forethought. This practice, of course, was not long tolerated, and Belgian block was substituted. It was found, however, that, except in very narrow roads, no travel ever came on the pavement except to cross it, and telford or macadam pavements were laid in the tracks, with an edging of trap rock block against the rails. Experience showed that blocks did not wear, and the macadam did. The result was that in a short time the blocks projected 1 or 2 ins. above the macadam. The later practice is now to leave out the edging and use macadam entirely. This, of course, is not applicable to steep grades, as the macadam will wash out in heavy rains from the concentration of the flow by the rails.

One serious difficulty encountered in the maintenance of macadam roads along rail tracks is the localization of travel in two parallel lines about 2 to 3 ft. from the outside rail, and it is found that the cost of repairs for the same distance is practically doubled, as telford roads originally requiring attention once in two or three years now have to be patched every year, and then with less satisfactory results.

One curious trouble found in laying the block edging against the rail on telford roads was that the sand designed to support the blocks was washed by the rains into the interstices of the foundations, letting the blocks down. Very coarse gravel and cinders used as a substitute for the sand removed the difficulty.

The concentration of travel into the parallel lines quickly caused ruts to be made, a very unusual experience to the author, and the solution of the difficulty has not yet been arrived at. Broken stone of larger size, up to 3 ins., is now being tried, and, so far, is an improvement, but the surface is rougher. This trouble, of course, only occurs when the tracks are in the center, and the driveways on the side. This brings up the question of the location of the tracks, and in

that the practice is varied. In cities as a rule the center is the only available place, and opinion is well crystallized in favor of that location; but in suburban roads the practice is varied.

On a 50-ft. roadway, a 20-ft. driveway in the center, a track on each side, and then 9 ft. for access to houses, gives good satisfaction, preserves the driveway, and lessens repairs. In a 60-ft. roadway and 14-ft. driveway outside the tracks, all the requirements are attained. In a roadway of less than 50 ft., the tracks of necessity must be in the center. Where only one track is laid on a country road, the track should be on one side, with switches towards the center.

The ideal road with trolley tracks is probably the extension of Beacon Street, Brookline, Mass. One wide roadway in the center, the trolley tracks sodded with grass, and a driveway on each side for local access give all the necessary facilities for the varying wants of the traveling public.

In the construction of Beacon Street, the company which owned the land opened the street, graded it, and was in sympathy, if not identical, with the trolley company. The result was perfection; but when a trolley company, the municipality and the property-owners are pulling in different directions, the doctrine of perfection is difficult to inculcate.

With the unexpected and enormous increase of travel on street railways due to low fares and increased speed, and a general appreciation of the profits derived therefrom, the public has gradually increased its demands upon the traction companies for the privileges conferred. The newness of the plants has so far rendered renewals unnecessary, and repairs and the cost of such repairs have not yet been fully appreciated; so that whether the companies will concede more to the communities, or will do less in the future, cannot be fully predicted. Until then, no permanent status of their relations can be fixed.

However, with the constantly increasing demand and insistence upon good pavements and highways, the practice, both of track and street maintenance, is bound to receive the thought and consideration of professional men, and if these few remarks shall be conducive only to that end, they will not be in vain.

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No. 802.

THE INFLUENCE OF RAILS ON STREET PAVEMENTS.

By EDWARD P. NORTH, M. Am. Soc. C. E.

PRESENTED DECEMBER 16TH, 1896.

WITH DISCUSSION.*

When the streets of cities were paved with granite or trap blocks, laid on a sand foundation, with a space varying from 1 in. to 2 ins. between the blocks, which was thought necessary to afford a foothold for the horse traffic, the section of the rail selected by surface railroad companies did not add materially to the unevenness of the pavement. As a matter of fact, the first rails used were so much of an improvement on the prevalent street pavements that the traffic early developed a tendency to follow the lines of the rails. As this retarded the railroad traffic through a natural unwillingness on the part of teamsters to pull out of the track, the Hewitt or center-bearing rail, Fig. 1, was invented, with the avowed purpose of preventing vehicular traffic following the lines of the rails. While this rail is probably as obstructive to traffic crossing it at a sharp angle as any street rail ever invented,

* The discussion on Papers Nos. 801 and 802 was a joint one. and will be found on pages 78 to 132.

its very brutality partially defeated its object, as a heavily loaded wagon once on the line of such rails leaves it with extreme reluctance. It is, however, largely employed on the surface roads of the city of New York, and it has required an act of the legislature to prevent a further extension of its use. A modification of this rail, Fig. 9, has also been introduced, and is used as a girder rail on one of the cable lines in this city.

The side-bearing rail shown in Fig. 4 as a girder rail presents a very good wheelway for vehicles once between the rails, and thus far is better than the Hewitt rail; but on account of its nearly vertical sides, it is very hard to pull a loaded wagon out of the track, and in crossing at a small angle with a light vehicle at any speed, the jerk is about as severe as on the center-bearing rail. A rail of this section is also used as a strap rail, being spiked to longitudinal stringers, as is the center-bearing rail generally.

Figs. 7 and 8 show sections that are employed as guard rails on curves and otherwise. They also are strap rails, and when laid on curves, it is almost impossible to make the spikes hold so well that water will not splash out from under them. The only excuse for their use is that bending them costs less than bending a girder rail, and, in general, the use of a strap rail on any highway should be prohibited after a near date in all self-respecting countries.

When permission was given to lay a cable road on Broadway, in New York City, both the previously mentioned forms of rail were so strenuously objected to that the Commissioner of Public Works prescribed a grooved rail, as shown in Fig. 5. This was followed on the Third Avenue line by a rail shown in Fig. 2, and on the Twenty-eighth and Twenty-ninth Street road the section shown in Fig. 6 was adopted. All of these rails are improvements on any of the forms of rails before mentioned, but all of them are objectionable in that the flange is lower than the tread, which results in an unnecessary unevenness in the pavement, and in Fig. 6 the slot is so narrow and the sides so steep that there is difficulty in keeping it clean.

In the spring of 1895, the Metropolitan Traction Company, intending to lengthen its lines materially, presented to the Commissioner of Public Works, through the Hon. John D. Crimmins, at that time its managing director, a form of rail which, after some slight modification, was adopted. It is shown in Fig. 3. Except that the rail should

have been 9 ins. deep, instead of only 7, this section is possibly the best that has been introduced in this country.

There is abundant depth for the wheel flanges, while the curved flange on the rail allows obstructions to pass out easily, and materially aids a narrow-tired carriage wheel in getting out, as, the moment it assumes any angle, it is lifted up the curve by the reaction against the nearly vertical sides of the tread.

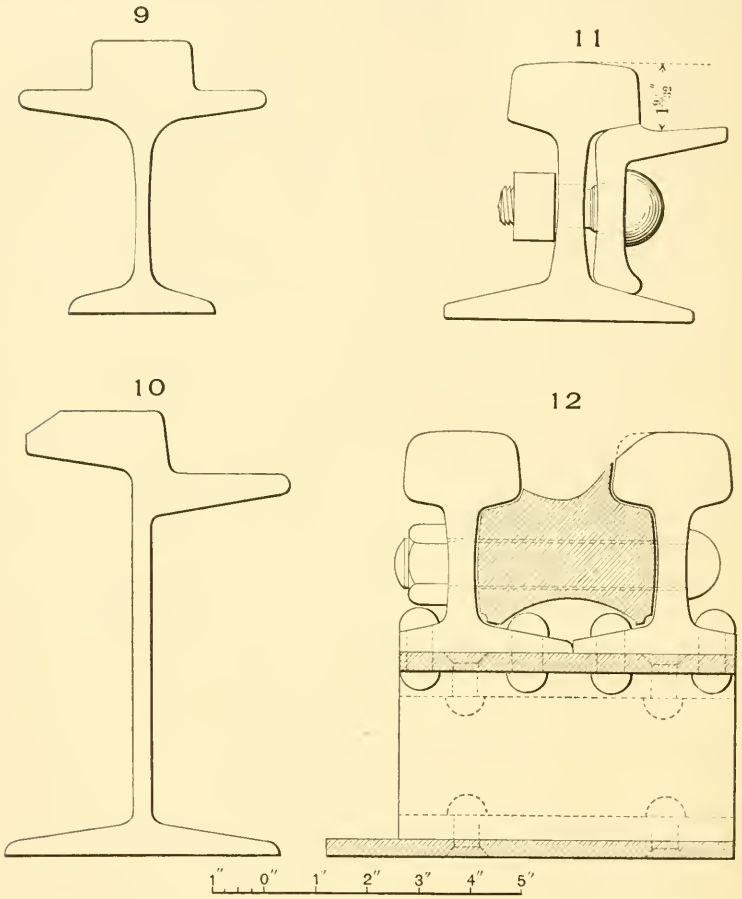
The value of this rail depends on the fact that the slot is so narrow that the wheels of a truck cannot sink into it, and, with the pavement just flush with the tread and flange, there is nothing to keep a wheel on it, so that, not only will there be no difficulty in pulling out of it, but horses will not be constantly reminded by an increase of traction that it is their duty to follow the line of the rail. In fact where this rail has been laid, no wagon with a tire over 1½ ins. wide has been observed by the author to follow it, though when a light wagon is once in it, the horse inclines to follow the rail. This, however, results in minimum annoyance to the railroad company, as light vehicles are nearly always prompt to leave the line of rails on the approach of a car, however difficult it may be. One other form of side-bearing rail, Fig. 10, is shown. This rail has not been laid in the City of New York, though the Commissioner of Public Works was approached by a surface railroad company that wished to lay it. It will be noticed that it is a side-bearing rail, with some of the vices of the Hewitt rail added. Undoubtedly, if its use had been permitted, it would have accomplished its object, namely, the confiscation of about 15 ft. of one of the principal lines of traffic.

Heretofore, where it has been thought necessary to use T rails in the streets of a city, for the passage of either trains or isolated freight cars, the stones have not been paved near the inner side of the rail, but a space of 2 or 3 ins. between the rail and the stones is left, which often becomes of profound depth. Walter Katté, M. Am. Soc. C. E., Chief Engineer of the New York Central and Hudson River Railroad, devised the compound section shown in Fig. 11. This combination allows the paving blocks to have a side-bearing near their top, on the flange side of the rail, and prevents any wheel which parallels the rail dropping indefinitely between the paving blocks and the rail. The clearance for the wheel flanges, however, is unnecessarily great, as is also the depth for their accommodation, and, on the outside of the

1
2
3
4
5
6
7
8
1″ 0 1″ 2″ 3″ 4″ 5″ 6″

rail, the paving block can only be brought in contact with the head of the rail by chipping off a corner, which every one knows is extremely unsatisfactory, as it is almost impossible to keep a paving block in position which has been so treated.

When the Central Railroad Company of New Jersey applied to the



Commissioner of Public Works of this city for permission to cross Eleventh and Thirteenth Avenues near Fifteenth Street, with tracks leading from a car ferry landing to its yard west of Eleventh avenue, Mr. J. H. Thompson, its Engineer of Construction, presented a combination shown in Fig. 12. The rails used were the standard 60-lb. rails of the

road, with a cast-iron filler between them, and a corner of the guard rail cut off; the lower flanges of these rails, as shown, are also planed off, and the combination is bolted to a wrought-iron chair. This combination, it will be observed, gives a nearly perfect side-bearing to the paving blocks, so that they can be laid without chipping, and it is hoped will keep their place rigorously. The cast-iron filler is so formed that, with the planed-off corner of the guard rail, any wheel can get out of the slot with ease. The clearance between the two rails is left as wide as it is, because a part of the track is laid on a 16° curve. This is submitted as the best combination yet offered by any railroad company for taking steam traffic through the streets of a city.

The satisfactory adjustment of the pavement to the rails presents some difficulties. Stone blocks can be solidly laid against wooden stringers, but the stringers soon rot sufficiently to let the rail down, and the joint then becomes unsatisfactory. With all girder rails of such section that both the tread and top flange are as wide, or wider, than the bottom flange, hard terra-cotta fillers moulded to the concave lines of the section and set in cement mortar give good bearings for the blocks. It is always advantageous, however, to have the height of the girder rail greater than the depth of the paving blocks. In setting these blocks the surface of the concrete should be left low, and the blocks next the rails laid in cement mortar. All ramming should be done before the initial set of the cement.

An asphalt pavement cannot be laid successfully against a wooden stringer ; in such cases toothing blocks are a necessity. With girder rails the noise from toothing blocks may be obviated by their omission. The first cost is less, but the maintenance account will be greater, as the rails so absorb and hold the heat during hot summer days that the asphalt next to them is kept soft for some time after sundown, and if the traffic follows the rails, a crease is formed that requires repairs, which the railways are generally slow to make. When granite toothing is laid, it is better to lay alternating blocks of 6 and 12-in. lengths at right angles to the rail. Eight-inch headers and stretchers are sometimes laid, but they are not economical, except on streets of very light traffic.

In place of granite or brick toothing a steel plate about $\frac{3}{8}$ in. thick and 3 ft. wide, punched with staggered holes, has been offered. As the arrangement was patented, its specification in any contract

with the city was prohibited by law. A small piece of this plate was laid in Chambers Street, where it was very satisfactory, preventing the formation of any rut.

While the section of rail adopted for most of the surface roads is obstructive to the rights and interests of the public, the style in which the space between the rails and between the tracks is maintained is often intentionally made much more obstructive. The laws of the State of New York,* make it obligatory on all surface roads to pave and keep in repair the space between the rails and tracks and 2 ft. outside of the same, but it provides no adequate penalty for non-compliance with the law. The only recourse known in the City of New York is to pave the space and charge it to the railway company, or to leave the area to the public spirit of the corporations. Eighth Avenue from Thirteenth to Fifty-ninth Street shows the result of one course ; the other method has resulted in hills aggregating decidedly over $700 000 accumulating against the surface railways on Manhattan Island from 1889 to 1895, both years inclusive.

What may be termed the Eighth Avenue method has resulted in a pavement between the rails that is seldom used by even the most stolid truckman, while the space between the tracks defies traffic of all kinds. That company has in effect sequestered a strip on Eighth Avenue over 2 miles long and about 17 ft. wide, with no other warrant than a right of way for its cars. The injury to the property on that avenue and the increased cost of transportation in the city is so great that it seems inexplicable that no grand jury should have found a bill against the perpetrators of so malicious an outrage.

On the other hand, the plan of charging the cost of an improved pavement against the company, whose income is augmented by the increased value and greater circulation that follows better pavements, has cost the city on an average over $100 000 per annum for the past seven years. This money has been taken from the resources of the tax-payers, but it does not follow that it has resulted in a like gain to the corporations which so persistently and successfully defy the laws of this State.

It might not be worth while to occupy the attention of the Society with this question if it was a local one, but both in cities and on country roads the surface railways, whether actuated by horse-power

* Chapter 565, Section 98, Laws of 1890, as amended by Chapter 676, Laws of 1892.

or electricity, devastate the highway, using an easement for a right of way on the roads and streets with a haughty disregard of the rights of others that should not be allowed if they were held in fee. In spite of low freight rates on railroads and water-courses, this country has been injured, and, to some extent, impoverished, through the high cost of transportation on country roads, consequent upon their generally wretched condition. Concurrently with a general effort to so improve the surface of roads and streets that both transportation and circulation shall be cheaper and pleasanter, the success of these efforts are found to be threatened by the legal inability of local authorities to force owners of surface roads to maintain the area within and about their tracks in fair condition.

Some surface roads have procured charters which do not require them to maintain the pavement in and about their tracks. These claim that no additional burden can be laid on them. If this proposition is correct, it would seem to a layman that no increased rate of taxation could be levied against this property, but there seems nothing to prevent legislation which will allow municipalities and local officers in charge of roads prompt redress against corporations that now occupy the time of our courts in successful efforts to slight a duty imposed by their charters, or by general laws under which they are incorporated. Nor is there anything to prevent such legislation as will require those who are exploiting new roads, which will occupy highways, to pave, maintain and repave a much larger portion of the road or street than at present.

DISCUSSION.

Mr. Lewis. NELSON P. LEWIS, M. Am. Soc. C. E.—The pre-emption of the most important streets of cities to-day by railroad corporations, with no regard for the purposes for which such streets were primarily designed, the failure of the companies to live up to their charter obligations as to maintenance of pavements, and the frequent indifference and almost universal inability of public officials to secure from them a proper performance of their obligations, is one of the most conspicuous defects in modern municipal government in America. The manner in which sweeping franchises have been granted for an indefinite period for the occupation of the streets, with no attempt to protect the interests of city or citizen, can be characterized only as a stupendous piece of municipal folly, if not of municipal crime. There can be no proper reason why any future grants of this character should not be made for a fixed period, upon the expiration of which the road-bed and rails, if not the equipment, should become the property of the city, and all corporate or private rights in or to the streets become extinguished. However, conditions must be accepted as found. The charter and franchises have already been granted, and it is extremely probable that many more miles of street railroads will be built with no further restrictions than have already been imposed.

The questions now presented are: the proper construction, of such a character that it is possible to maintain a modern pavement along and between the tracks, and a guaranty of subsequent maintenance of pavement as well as track by the railroad company.

In construction the objects to be attained are durability, in order that the street surface need not be perpetually torn up for repairs, and the selection of a form of rail which will offer no obstruction to vehicles traveling along or across it, but will not invite them to follow it, and will not materially break the uniformity of surface of the pavement. The introduction of electricity as a motive power, with the enormous increase in the weight of cars, has resulted in the use of extremely heavy rails weighing from 90 to 100 lbs. per yard. The common method of track building with these rails presents a curious anomaly. Wooden cross-ties are placed upon soft earth and brought to a temporary surface by careless tamping. Upon them are laid heavy 9-in. girder rails, and the pavement is restored. It is only a matter of weeks or months before the tracks require resurfacing, and a perpetual tearing up of the pavement begins and continues for an indefinite period. Attempts have been made to improve upon this by laying a bed of concrete not less than 6 ins. in depth beneath the cross-ties, which are embedded in concrete. This has been done in Cincinnati, where sawed white oak ties are used, and the concrete is carried to the tops of the

ties where granite pavement is to be laid, or within 3 ins. of the top of the rail in the case of asphalt. Mr. H. J. Stanley, City Engineer, states that in over 40 miles of this construction which has been down several years no weak spots have developed. Full-grooved girder rails are used, 6 ins. deep on asphalt streets, and 8 ins. deep when granite or brick are to be used, and weighing, respectively, 86 and 95 lbs. per yard. Of course this is very expensive, but the railroad companies seem satisfied with the results. Samuel Whinery, M. Am. Soc. C. E., writes that in his opinion, a "broken stone foundation is entirely sufficient, and it offers opportunity for drainage, which is of advantage." Mr. Lewis.

In Toronto, Canada, under the direction of E. H. Keating, M. Am. Soc. C. E., what seems a further advance has been made in dispensing with the cross-ties altogether and laying 7-in. grooved girder rails directly upon a bed of concrete extending across the whole roadway, the concrete being apparently of the same thickness and quality under the rails as on the remainder of the roadway, the rails being kept to gauge by $2\frac{1}{4} \times \frac{3}{8}$-in. tie-rods. Mr. Keating says that the results in this case have been very satisfactory. In Minneapolis and St. Paul, the rails are laid on a longitudinal beam of Portland cement concrete.

In the opinion of the speaker the substitution of Portland cement concrete for perishable wooden cross-ties, as a support for the rails, is an important step towards a permanent track construction which will avoid the constant opening of the pavement for repairs.

Next as to the form of rail to be used. The side-bearing girder rail so generally in use at present divides the street pavement, if laid flush with the tread on one side and the flange on the other, into five sections, two of which are from 1 to $1\frac{1}{2}$ ins. below the remaining three; while in case granite blocks between the rails are laid at the level of the tread four troughs about 3 ins. wide will be left in the pavement. In either case the broad head presents irresistible attractions to the drivers of heavily loaded vehicles. The first efforts to remedy this trouble were naturally by the adoption of a grooved rail. The full-grooved rail, however, in which the flange and the tread are at the same elevation, was and is strongly opposed by the railroad companies on account of the difficulty of keeping the slot clean, and, it is claimed, of the danger due to inability to stop the cars quickly when the openings become filled with horse droppings, etc., and the great wear on, and breaking of, the wheel flanges when the groove is narrow. Grooved rails are being used to-day in a number of cities, including Washington, Cincinnati, Detroit and Buffalo, in which last a half-grooved rail (Fig. 13) was voluntarily adopted by the traction companies. The real reason for the objection is probably the greater cost of this form of rail. Few of the grooves are so narrow that wheels of light wagons will not get into them, and if the form recommended by Mr. North and shown in Fig. 3 be used, the writer fears that the

Mr. Lewis. noise made by wheels grinding along the curved flange and falling back into the grooves will be the cause of much complaint.

When electric traction was introduced in Brooklyn, the company operating a very large proportion of the total mileage of surface lines adopted what was known as the Lewis & Fowler girder rail, shown in Fig. 14. The municipal authorities appear to have acquiesced either from indifference or because the rail appeared to be a favorable one to lay pavement against. It would be difficult to design a section having the same amount of metal so disposed as to be less effective, and the failure which might have been predicted soon resulted. A serious objection to this form of rail was the noise caused by vehicles running on it when the wheels crowded first one side and then the other; the sound can be best described as a shriek.

There were at one time about 124 miles of single track on this system laid with this rail, and there are now 96⅔ miles, while there have been laid 101½ miles of 9-in. side-bearing girder, weighing 94 lbs. to the

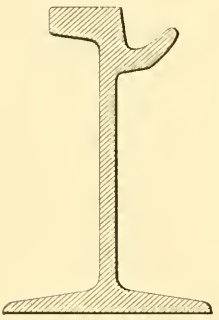


FIG. 13.

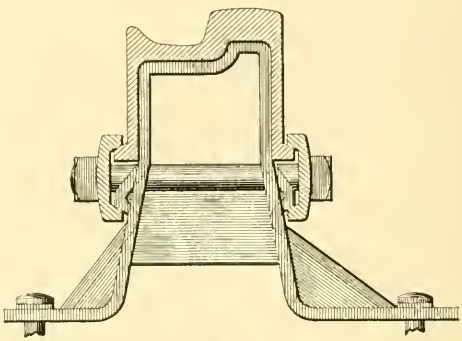


FIG. 14.

yard. The side-bearing girder is less objectionable in that less frequent repairs are required, but it breaks the surface of the pavement in a disagreeable way, and wagons tend to follow the rails and leave them with reluctance.

All the surface railroad companies in Brooklyn have been notified that no more rail of this type can be laid, and they have been requested to confer with each other, and submit designs for a standard section of a grooved rail or some form which will admit of the pavement on both sides of the rail being maintained at the same level.

The writer is of the opinion that in many cases there can be no reasonable objection to the use of a T-rail 7 or 9 ins. in depth. Kent Avenue, upon which are located large sugar refineries, sustains a very heavy traffic. Loaded trucks almost invariably travel with two wheels on the rails, while the other two soon cut a deep rut in the paving blocks about 15 ins. outside the outer rail, so that granite pavement

laid upon sand cannot be kept in passable condition for more than two years. The American Sugar Refining Company and the Brooklyn Heights Railroad Company offered this year to contribute one-half of the expense of laying a new granite pavement on a Portland cement concrete foundation. It would have seemed wise to defer this improvement until some form of rail should be adopted which would present no obstruction to wagons, and yet offer no inducements to them to follow it. One track, however, has been relaid, and one side of the street paved this year. The writer has suggested to the railroad company the adoption of the form of construction shown in Fig. 15. for the remaining track. The rail is a 9-in. T, weighing 78 lbs. per yard, should be in 60-ft. lengths, and laid with cast-welded joints. Tie bars at intervals of about 10 ft. would prevent spreading. The rail would undoubtedly last twice as long as that used in the other track, there would be almost no break in the surface of the pavement, and no obstruction to the passage of vehicles along or across it, while they could not follow it, and the traffic would be more evenly distributed over the entire paved surface. The blocks next to the rail would be set in cement mortar, and those on the inside would have the cor- Mr. Lewis.

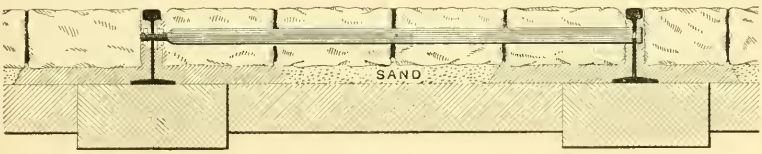


FIG. 15.

ners slightly chamfered off, giving room for the wheel flanges. While it may be almost impossible to keep a paving block from which the corner has been chipped in position along the inside of a side-bearing rail when every wheel turning out of the track has to mount the block, there is no reason why such blocks cannot be kept in position along the rail proposed, nor why the wear should be very great. A trial under these conditions would soon demonstrate the merits or defects of this form of construction.

There is little doubt but that such a rail laid in this manner would give very satisfactory results in connection with asphalt pavement. A street in Minneapolis upon which track was so laid was paved with asphalt carried close to the rails on both sides, and the flange groove was formed by running a heavily loaded car over it as soon as the asphalt had been laid and rolled. F. W. Cappelen, M. Am. Soc. C. E., states that the asphalt has not as yet wrinkled or disintegrated along the rail. The use of unsightly granite or other toothing is thus avoided, and the asphalt will be much less difficult to maintain than it is when laid along the side-bearing girder.

Mr. Lewis. The cast-welded joints above referred to can no longer be called an experiment. One railroad company in Brooklyn had about 1 600 of them made on new 9-in. girder rails, of which but one has failed in the six months of service to which they have been subject. The cost was $3 75 each. Another company had over 2 000 joints made on old 4½-in. girder rail, about 40 of which have broken. This method of making joints is undoubtedly more successful with new and deep rails than in the case of old and lighter ones.

For suburban lines and on macadamized streets and roads a T-rail laid on cross-ties will doubtless give good satisfaction, toothing of granite blocks being used along the rails on heavy grades to prevent the washing out of the macadam. Even though it should require more care to keep a stone pavement in repair along rails of this section, the resulting economy to the railroad company through the longer life of the rail would more than compensate them.

Good track construction is a question in which the railroad corporations and the municipality are both interested, so that it should not be very difficult of attainment. Not so with the maintenance of the pavement after the tracks have been built. The railroad companies will do no more than they are required, and nothing if they can avoid it. The conditions prevailing in any one city will be of more interest than general statements.

The charters held by the Brooklyn companies provide that they "shall at all times keep in good repair the pavement of the streets through which their rails may be laid, between the tracks and for three feet on each side thereof." This has been interpreted by the companies to mean that they shall restore the pavement to as good condition as it was in before the tracks were laid, but that when the sides of the street are relaid with a new pavement they cannot be asked to make a corresponding change in that part between their tracks.

The president of one of the principal systems in Brooklyn, upon applying for a permit to lay new rails upon one of the widest streets in the city, the sides of which had just been paved with granite without expense to his company, was told that he should in relaying the pavement substitute granite for cobblestone. He protested against being compelled to do so, and seriously gave as a reason that if the pavement between the tracks should be such as to attract travel to it there would be much greater danger of those using it being injured by his cars. The tracks were rebuilt and the cobblestones were relaid.

The Brooklyn charter in providing for the repaving of streets says: "That no street or avenue over or through which a railroad is operated shall be so repaved unless the owner or owners of the franchise of such railroad shall first contribute a just and reasonable portion of the expense thereof, to be determined by the Commissioner of City Works." This requirement has been generally ignored and many miles of granite

pavement have been laid upon railroad streets towards the expense of which the companies have contributed nothing. Within the last two years, however, they have done somewhat better. One company has contributed one-fourth of the entire expense of repaving five important thoroughfares. Two other companies declined to contribute anything, and after the work was completed suit was brought against them for the cost of that portion of the new pavement between their tracks and rails. It is needless to say that the suits have not yet come to trial. The local improvement law enacted in 1895 provides "that in all cases when a surface railroad is laid and operated through any such street, one-fourth of the cost of such repavement shall be assessed upon such railroad, and one-fourth thereof on the other property benefited within the district of assessment," the remaining half being paid by the city at large. One street has been repaved with granite, and one with asphalt under this law, and the assessment, being a lien upon the railroad, can be collected. This only provides for repaving where an assessment is laid upon private property for a portion of the cost. Upon streets where an assessment has once been laid for an improved

Mr. Lewis.

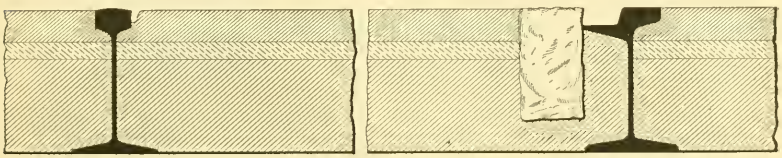


FIG. 16.

pavement the entire cost is paid by the city, and there is nothing but the charter provision calling for a contribution from the railroad companies, and that is so indefinite in its requirements that it amounts to but little.

With more perfect track construction and the use of a rail which will not be followed by vehicles, nearly all the traffic will follow the sides of the street and the pavement between the tracks will not require as frequent renewal as that outside. Much has been accomplished recently, however. The continuity of the asphalt pavement was broken by railroad crossings in a disagreeable manner, especially for drivers and wheelmen. At twenty-five such intersections the railroad companies have paid the cost of paving the entire spaces between their rails and tracks. The manner in which the pavement was laid along the rails is shown by Fig. 16, square cut granite blocks having been laid in Portland cement mortar along the inside of each rail, and the joints filled with grout. The blocks were set at the elevation of the tread of the rail. Pieces of granite of the same thickness and depth but 3 or 4 ft. long were used in several cases, but the results were not

Mr. Lewis. as good as when paving blocks 12 to 14 ins. in length were used. The result has been very satisfactory, and there is scarcely any perceptible shock in riding across them. On several streets where the sides are paved with asphalt and the track spaces with stone, the granite toothing has been removed by the railroad companies, and the asphalt carried directly up to the outside of the rail, greatly improving the appearance of the street. The suggestion that this should be done at the expense of the railroad companies, would, three years ago, have been ridiculed by them.

This problem must be solved under the authority of the laws as they exist at present, unless they can be modified. These are unsatisfactory, but notwithstanding this fact, if the whole matter could be placed in the hands of municipal engineers, who were unembarrassed by the consciousness or hope of a political future, and taken up by them with firmness and fairness towards the corporations, there would soon be a marked change for the better.

Mr. Pratt. Mason D. Pratt, Assoc. M. Am. Soc. C. E.—In studying the subject of the best form of rail and track construction for city streets where traffic is heavy, some aid may be had by looking carefully into the existing conditions, and seeing what effect the several sections of rail have had on the pavements as laid. This may lead to modifications of the sections which will tend to prevent any injurious effects.

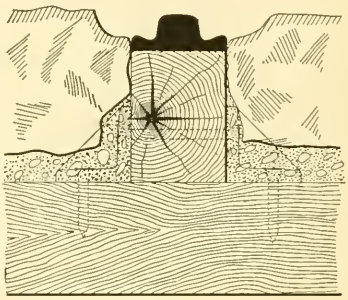


Fig. 17.

Fig. 17 shows the rail of the old horse-car tracks in New York City, which have by far the greatest mileage to-day. The time for their reconstruction is rapidly approaching, as New York is far behind all the other large cities in the matter of improved traction. The drawing very clearly shows the objectionable features mentioned by Mr. North, when the pavement is laid to line with the top surface of the rail. In many cases the pavements have gone down, and the entire head of the rail projects above the general street surface.

Fig. 18 is a partial section of the Broadway cable road. It is not peculiar to any one portion of the road, but fairly represents the conditions for the major part of its length. The paving blocks rest on a concrete bed, with but an inch of sand between, giving a practically unyielding bed. The illustration clearly shows the adhesion to an old practice in paving, where the foundation was not so well made and was of a more yielding nature; reference is made to the height of the paving blocks above the head of the rail. In pave-

ments, as ordinarily laid, it is expected that they will sink more or Mr. Pratt.
less under the action of traffic and weather, and it was customary to set the stones $\frac{1}{2}$ in. or more above the rail. The wisdom of so doing was realized when the blocks did sink, often not stopping at the rail level. This will be found to be the case with many of the old tracks, like Fig. 17, which shows the pavement in its best condition. In the case of the Broadway road, and all others where there is a concrete base, the pavement has remained just where it was put, with the re-

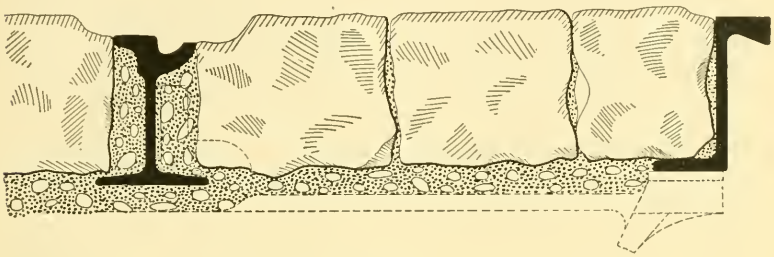


FIG. 18.

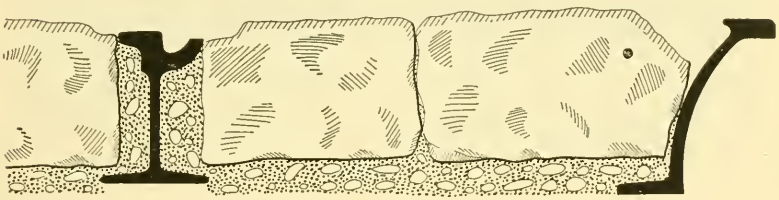


FIG. 19.

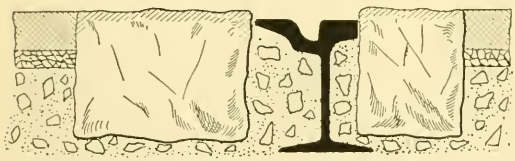


FIG. 20.

FIG. 21.

sult that there is a deep rut along each line of rails, the bottom of which is on a level with the rail head or tram. The same is true of the track of the Third Avenue cable road, Fig. 19, and will be so of the tracks now being laid in First Avenue in asphalt with granite toothing block, Fig. 20.

Fig. 21 shows part of a track laid with the improved rail mentioned by Mr. North, in asphalt pavement in One Hundred and Sixth Street. This is a very broad street, no cars have ever run on these

Mr. Pratt. tracks, and the street traffic is very light, so there is no guide as to what the results would have been under the conditions existing in most of the streets in the city.

Fig. 22 shows a part of a cable track in asphalt pavement in One Hundred and Sixteenth Street. The hollow on the inside of each track rail shows where the wear, due to vehicular traffic, has been concentrated.

It will be admitted, of course, that the most desirable condition for the surface of a street is one uninterrupted by ruts, grooves or other irregularities. It will also probably be admitted that the greatest life will be had from a pavement where the traffic is distributed over its entire surface, and that the pavement will suffer most when the traffic is concentrated along certain portions. The greatest damage is done to pavements by trucks and other heavy vehicles, and it is they that are constantly seeking the path of least resistance. This is, of course, along the rails, and where the rail is of such form that the tram, or guard portion, is lower than the head, no matter

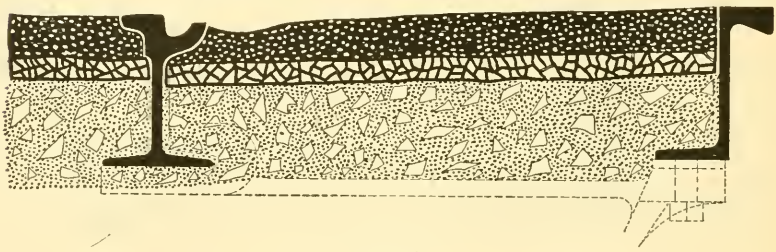


Fig. 22.

how little, there is a guiding shoulder which keeps the wheels in the tracks without any effort on the part of the driver. Comparatively few of the heavy trucks and drays have the same gauge of wheels as the railway tracks, but this in no way prevents their following the tracks, for one wheel will ride on the shelf of the rail, while the other follows a parallel path just outside the other rail. As there are many trucks of each class, it will be found that this concentration of wear has its effect in an appreciable trough along the outer rail and about 6 to 10 ins. away.

The same result will be had in the case of the improved form of rail, Fig. 23, where the pavement is laid as shown by Fig. 20.

The head of a perfect rail should be level, with a groove or flangeway only sufficiently large to pass the wheel flange freely, and of such shape that dirt, ice and similar obstructions will be easily worked out by the flanges themselves. The groove in the rail, Figs. 23, 24 and 25, does this admirably. Fig. 26 is the section of rail adopted in Washington, D. C., where all the streets are paved with asphalt and

kept clean. The wheel flanges are necessarily smaller than those in general use elsewhere. Mr. Pratt.

There is one peculiar feature in the three sections just mentioned, namely, the extended lip on the tram. Just what use this serves it is difficult to see. It is possible that it had its origin in the idea that the immense traffic concentrated along the Broadway cable and other roads required a more substantial track than that offered by the lip of the rail in use on that road. This would be the case if it had been left at a lower elevation than the head, as, for instance, in the section shown in Fig. 24, but as before stated, it is for the good of the pavement that the street traffic be not invited to follow the track. When the rail head is level and the pavement laid flush with it, there is nothing to guide traffic along the tracks, and it will wander from the rail and distribute itself over more of the street surface. This being the case, there is no use whatever for a broad lip, which but adds so much more to the smooth steel surface for horses to slip on.

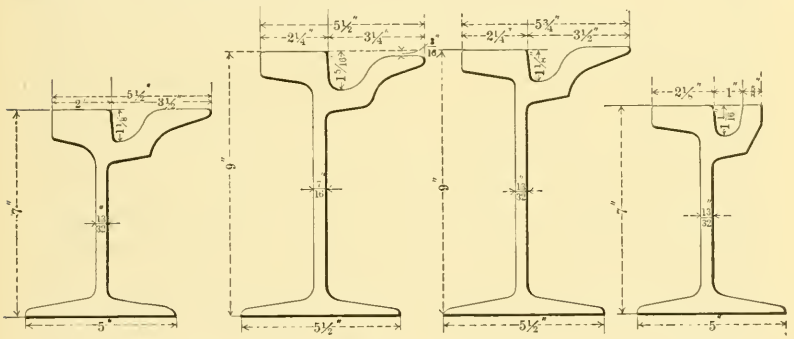


FIG. 23. FIG. 24. FIG. 25. FIG. 26.

The Society was instrumental, a few years ago, in throwing considerable light on the question of standard rail sections for steam roads, and it is reasonable to think that a similar investigation into this subject may result in even more good to the street railways.

GEORGE E. WARING, Esq.*—A calculation recently made, which may seem extravagant, although the facts will sustain it, shows that if all the streets in New York City of suitable grade were asphalted, and if all the street railway tracks were like that shown in Fig. 21, with no considerable space to receive dirt and make them difficult to sweep, the $1 200 000 now paid out annually for street sweeping alone would be reduced to $700 000. This shows that the City of New York could very well afford, at its own cost, to set aside all questions of the obligations of railroad companies, and reconstruct all city railways on which the tracks are not now what they should be. Mr. Waring.

* Commissioner of Street Cleaning, New York City.

Mr. Reed. W. Boardman Reed, Assoc. M. Am. Soc. C. E.—The subject of rails for street railways, and especially their influence on street pavements, is one that has received but little attention from engineers until within a few years; but the recent great increase in mileage of street railways, the growing demand for good roads, the fact that the weight of rolling stock can well be compared with that on steam roads, and the almost phenomenal increase of traffic on street car lines, makes it well worthy of attention.

Whether the prime object of the designers of the center-bearing or Hewitt rail was to keep trucks and other vehicles from following the tracks the speaker could not say, though that seems to be the generally accepted opinion. If so, it certainly failed to accomplish this result, for in New York, where there are more miles of center-bearing rail than of all other sections, drivers, especially when their wagons are heavily loaded, follow the track upon which this rail is laid as persistently as any other. Without doubt, however, this is the most desirable rail from a strictly railway standpoint; having a tram or flange on either side, dirt, slush or snow does not remain on the head, the car wheels themselves pushing such obstructions to either side and thus keeping it constantly clean. On account of the double tram, however, there is twice the annoyance to vehicular traffic that there is with almost any other section of rail. The pavement being set level with the head of the rail, a space is left on either side of the tread of the rail about 1½ ins. wide and of a depth equal to the distance from the head to the tram of the rail, about 1 in. Vehicles follow along on either side of the rail and soon wear the pavement away, so the space is increased to about 4 ins. in width or a little wider than the usual tire. The ram is so narrow that truck wheels do not ride it well, making the pavement wear more, and ruts are soon cut which are extremely dangerous.

The rail almost universally used throughout this country on street railways constructed or rebuilt within the past few years is the side-bearing rail, a section of which is shown in Fig. 4. It is a great improvement over the center-bearing rail so far as influence on street pavement is concerned. The pavement is laid next to the outside of the head and about level with it, so there is no rut ready made for vehicles to run in, and the pavement next to the outside of the rails does not wear much faster than any other portion of the street, thus reducing the cost of maintenance of the pavement nearly one-half, as compared with the cost with the center-bearing rail. On the inside of the rail there is a tram 3 ins. wide which carries the wheels of all vehicles having less than 3-in. tires. If the pavement in the track is laid level with the top of the tram, wheels of vehicles following the rails cut no rut and it is easier to turn out of the rails with a wagon than if the paving stones are left above it. It seems to have been

the universal custom, however, to keep the pavement, even in the track, level with the head of the rail, thus leaving a groove or rut similar to that found with center-bearing rails, except that the extra width of tram carries vehicles more easily and the pavement is simply worn back an inch or so on the edge and then rounded off, preventing dangerous ruts. Of course at intersecting streets where wagons cross the tracks at obtuse angles the pavement should be left level with the head of the rails to avoid the jolt that otherwise would occur. Mr. Reed.

The sections of rail shown in Figs. 2 and 5 have some advantages over the center-bearing and side-bearing rails for vehicular travel, but, like any grooved rail, are objectionable to railway companies on account of the difficulty of keeping the groove clean. The tram being bent up so that it is $\frac{5}{16}$ in. below the head, and the groove being but 1¼ ins. wide, it is much easier for vehicles to turn out of it than out of either of the previously mentioned sections. It has the same advantage as to pavement on the outside as the side-bearing rail, but it was found on Broadway, New York, that trucks following the rail soon wore a rut in the pavement next to the tram, and the cost of maintenance of pavement on this account was excessive. To remedy this evil, Mr. L. J. Hirt, formerly assistant chief engineer of the Metropolitan Traction Company, and the speaker decided it would be well to increase the width of the tram sufficiently to carry the trucks, and thus save this excessive wear on the pavement. A section was designed similar to that shown in Fig. 3, except the tram was $\frac{5}{16}$ in. below the head. The Department of Public Works, however, upon the recommendation of Mr. North, insisted that this tram be raised to the level of the head giving the section shown in Fig. 3. The raising of the tram makes it impossible to keep the dirt out of the groove by any scraper attached to a car, and it is possible to keep it clean only with hand scrapers and brooms. None of this section of rail has as yet been used to any extent in winter weather, but, judging from the amount of labor required to keep it clean under ordinary circumstances, it is feared it will be well nigh impossible to keep it free from snow and ice without a plentiful use of salt, which is condemned by the Boards of Health, Society for the Prevention of Cruelty to Animals, and on electric roads by the electricians. Of course, with cable or horse power a dirty rail is not as objectionable as it is with self-contained motor cars, and with the use of electric or compressed air this rail would cause much trouble, and still more trouble if the rails were used for a return circuit as on the trolley roads. Had the tram been left as originally designed, the trouble in this direction would be greatly lessened, and yet there would have been no appreciable difference to vehicular traffic. It is interesting in this connection to note the change recently made in the style of rails in England, where they have insisted, as some American authorities now insist, upon the head and tram being

Mr. Reed. the same height. Within a few months the authorities there have required the section to be changed so as to bring the tram below the head.

No section of rail has as yet been rolled suitable for steam railroad cars and locomotives for streets. Various methods, therefore, have been adopted to utilize the T-rail. The method used by the Central Railroad of New Jersey is a good one, but much too expensive for general use, and it necessitates the use of chairs 3½ or 4 ins. high, which make the structure weak. As the gauge of freight cars varies and the flanges are as much as 1½ ins. deep, it would be impossible to design a rail suitable for them that would not offer more or less impediment to vehicular traffic.

Stringer construction, so-called, is almost a thing of the past, and of but little interest except as a matter of history. The flat rail on timbers is not stable enough for modern cars, and in the few places where railroad companies have tried to use it with electric cars they have been confronted with snake heads, such as occurred in the early days of steam railroading.

This construction answers very well for horse-car traffic, and Mr. North's statement that the stringers soon rot and let the paving stones fall in is misleading. The writer has recently taken up stringers that have been down more than twenty years on a road where cars run on less than three minutes' headway; these stringers were badly decayed, but those fifteen years old were in a fair state of preservation, and certainly strong enough to hold up the pavement. Mr. North speaks of the joints on this style of construction. Where channel bars are used at the joints and care taken in boxing them into the timber, the joints stand up under heavy strain for some years. But little attention was formerly given to the joint, often nothing but a thin, flat iron being used, and on several miles of one of the most important lines in New York City there was not a single joint plate of any kind; it is no wonder that with such construction the joints went down, and made riding in either cars or wagons somewhat unpleasant.

With girder rails it is necessary, where paving blocks are set next to the rail, to use some kind of a filler between the upper and lower flanges. Creosoted wood, plain spruce plank, cement mortar and hard-burned terra-cotta bricks molded to fit the rail have been used. Until within the last two years, when the writer introduced the use of terra-cotta brick, mortar was used exclusively in New York. It answers the purpose as well as brick, but the cost of applying it, especially when cars are running over the rails during construction, is much greater than the brick. When asphalt pavement is laid against the rail, no filler is required.

Whenever two substances of different degrees of hardness are used next each other upon the surface of a street there is excessive wear at

their junction upon the softer, especially if they are joined together in a straight line. It is on this account that ruts are likely to be worn alongside the rails, and it is hard to see how increasing the width of the top of the rail to 18 or 20 ins., which would be the result of using the steel plate mentioned by Mr. North, would improve matters. If, however, the edge of this plate was toothed, thus giving the same result as granite toothing, it might answer equally as well as the stone, though even then the asphalt with which it is proposed to use this plate would probably show more wear than if stone was used. Mr. Reed.

As all heavy trucks are more than 4 ft. 8½-in. gauge, the standard gauge of street railroads, truck drivers follow one rail, thus throwing the opposite wheels about 18 ins. from the other rail. These outside wheels soon wear ruts in the hardest pavement and increase the cost of maintenance very much. To remedy this evil, the railroad companies in a number of cities, notably Philadelphia, Pa., Newark and, possibly, Jersey City, N. J., widened the gauge of their tracks, thus giving the heavy trucks metal tramways, but the trucks, once in the track, would not turn out, so the speed of cars was regulated by speed of trucks. Shortly after the introduction of electric cars, the gauge was brought to standard.

If the section of rail shown in Fig. 3 is used, and it is possible to maintain the pavement next to the rail level with it, trucks can not easily follow the rail and thus no such trouble as mentioned will arise, but as any pavement is softer than 0.55% to 0.65% carbon steel, which it is now proposed to use for street rails, the pavement will wear faster than the rail, and if originally laid flush with it, there will soon be more or less of a rut which vehicles will follow.

The speaker believes that granite or other stone pavement should be left ½ in. above the rail ; the corners will soon round off so there will be no difficulty in turning out, the life of pavement will be very much increased, and the cost of maintenance much decreased.

The statement made as to the effect of the obligations imposed by the laws of the State of New York on street railroads is plainly erroneous, as the statute does not require the roads to pave and keep in repair, but only requires them to have and keep in repair. The obligations as read by some of the city officials having charge of street pavement would require the railroad companies to lay new pavement whenever these gentlemen thought that bicycle or buggy riding would be benefited by it.

The statement contained in the paper is unfair to the railroad companies, as it seeks to bring all of them within the obligation of repairing the pavement. There are many railroads in the city of New York and other cities of this country having charters that do not contain any obligation whatsoever as to street paving, while it has been held, particularly in a suit of the City of New York against the Eighth

Mr. Reed. Avenue Railroad Company, that the railroad was not under any obligation to lay new pavement in the street. The court, in this case, held specifically, that unless such an obligation was imposed by the charter of the company or some contract entered into by it with the city, that the city could not lay new pavement and charge the cost against the company.

Although it is well known that it takes a long time to secure justice in many cases, it is very evident that if the city had claims against railroad companies for street paving arising in the year 1889, and if the city authorities believed they had any claims against the railroad companies, the case would have been pushed to an issue before the present time.

The latter part of the paper contains a statement that the surface railroads have procured charters which do not require them to maintain the pavement, and that they claim that no additional burden can be laid on them. This is an erroneous position to take of the law. The position of the companies has always been that the legislature has not made any effort or sought in the slightest degree to impose the obligation of repair or the furnishing or relaying of new pavement upon them.

With regard to the weight of cars used on street surface railways, the following data may be useful:

Ordinary single-truck cars with 18-ft. to 20-ft. bodies, a $6\frac{1}{2}$-ft. to 7-ft. wheel base, equipped with two G. E. 800 motors, and having a seating capacity of about twenty-four, weigh from $7\frac{1}{2}$ to $8\frac{1}{2}$ tons. Double-truck cars with 35-ft. bodies, a wheel base on each truck of 5 ft., and a distance between truck centers of 18 ft., equipped with G. E. 1 200 motors, and having a seating capacity of from forty to fifty, weigh from 20 to 23 tons. The trucks of these cars are usually arranged to carry about 75% of the load on the drivers, which should be considered in calculating wear on rails. Cars such as are used on the Metropolitan Street Railway Company's cable and electric roads in New York City have single trucks, an 8-ft. wheel base, bodies 32 ft. long, and a seating capacity of twenty-eight; the cable cars weigh about 7 tons, and those equipped with G. E. motors about 9 tons.

A few words should be added in defence of some of the recent track construction in New York City. Within the past few years the railway companies have been looking forward to a change in motive power, by which they would be relieved of further annoyance with horses. What the new motive power would be could not be foretold. Wherever the cable or underground trolley has been adopted permanent construction on yokes has been carried out, but all other lines have been to a greater or less extent of a temporary character, with the idea that it was only a matter of a year or two when they would be

replaced by some other type. The track on One Hundred and Sixth Street* was built with a view to greater permanence than the rest, except those of the yoke construction. The rails are laid on cross-ties 5 ft. apart, which also serve as tie-rods, and rest on a beam of concrete from 6 to 8 ins. thick and 15 ins. wide. The concrete is built up around the base of the rails and holds them in place. Mr. Reed.

G. J. Fiebeger, M. Am. Soc. C. E.—The construction of pavements along the street car tracks in the city of Washington is governed by the Act of Congress, June 11th, 1878, given below. Capt. Fiebeger.

The features to which attention is invited are the fifth, sixth and seventh paragraphs, which provide the means of keeping the pavements in repair, and of laying and relaying them if the railway company fails to comply with the provisions of the first paragraph.

The relaying of the old tracks with modern grooved girder rails was done in conformity to an Act of Congress of March 2d, 1889, also given below.

In carrying out the provisions of that act, the Commissioners, on the recommendation of the Engineer Department, adopted a rail with flange and head in the same horizontal plane and a groove 1 in. wide. This rail has given general satisfaction. Upon cable and underground trolley roads it is customary to pave the space between rails and tracks either with sheet asphalt or vitrified brick.

Extracts from an Act Providing a Permanent Form of Government for the District of Columbia.

* * * * * * * * *

The cost of laying down said pavements, sewers and other works, or of repairing the same, shall be paid for in the following proportions and manner, to wit: When any street or avenue through which a street railway runs shall be paved, such railway company shall bear all of the expense for that portion of the work lying between the exterior rails of the tracks of such roads, and for a distance of 2 ft. from and exterior to such track or tracks on each side thereof, and of keeping the same in repair.

But the said railway companies, having conformed to the grades established by the Commissioners, may use such cobblestone or Belgian blocks for paving their tracks, or the space between their tracks, as the Commissioners may direct.

The United States shall pay one-half of the cost of all work done under the provisions of this section, except that done by the railway companies, which payment shall be credited as part of the fifty per centum which the United States contributes toward the expenses of the District of Columbia for that year.

And all payments shall be made by the Secretary of the Treasury on the warrant or order of the Commissioners of the District of Columbia, or a majority thereof, in such amounts and at such times as they may deem safe and proper in view of the progress of the work.

* Of which a partial cross-section is shown in Fig. 21.

Capt. Fiebeger. That if any street railway company shall neglect or refuse to perform the work required by this act, said pavement shall be laid between the tracks and exterior thereto of such railway by the District of Columbia.

And if such company shall fail or refuse to pay the sum due from them in respect of the work done by or under the orders of the proper officials of said District, in such case of the neglect or refusal of such railway company to perform the work required as aforesaid, the Commissioners of the District of Columbia shall issue certificates of indebtedness against the property, real or personal, of such railway company, which certificates shall bear interest at the rate of 10% per annum until paid, and which, until they are paid, shall remain and be a lien upon the property on or against which they are issued, together with the franchise of said company.

And if the said certificates are not paid within one year, the said Commissioners of the District of Columbia may proceed to sell the property against which they are issued, or so much thereof as may be necessary to pay the amount due, such sale to be first duly advertised daily for one week in some newspaper published in the city of Washington, and to be at public auction to the highest bidder.

When street railways cross any street or avenue, the pavement between the tracks of such railway shall conform to the pavement used upon such street or avenue, and the companies owning these intersecting railroads shall pay for such pavements in the same manner and proportion as required of other railway companies under the provisions of this section.

* * * * * * * * *

Approved June 11th, 1878.

DISTRICT OF COLUMBIA APPROPRIATION BILL, 1890.

* * * * * * * * *

That any company authorized by law to run cars propelled by horses in the District of Columbia is hereby authorized to substitute for horses electric power by storage or independent electrical batteries or underground wire, or underground cables moved by steam power, on the whole or any portion of its roadway, with authority to purchase and use any terminal grounds and facilities necessary for the purpose; and any such street railway electing to substitute such power on any part of its tracks or road-beds on the streets of the District of Columbia shall, before doing so, cause such part of its road-beds to be laid with a flat grooved rail, and made level with the surface of the streets upon each side of said tracks or road-beds, so that no obstruction shall be presented to vehicles passing over said tracks: *Provided*, That in the event said companies or either of them shall fail for the period of two years from the passage of this act to exercise the powers and privileges hereinbefore given, such companies are hereby required to cause said rails and roadbeds to be relaid with the flat grooved rail hereinbefore mentioned, so as to be level with the surface of the streets upon each side of said tracks or roadbeds and the cost of making the changes hereinbefore required shall be paid by the corporations or persons owning or operating said street railroads, and if, after being notified by the Commissioners of the District of Columbia in writing to comply with the terms of this act, the said corporations

or either of them shall not within ninety days thereafter begin the work required and complete the same within a reasonable time, not more than twelve months from the expiration of said period of ninety days, it shall be the duty of the Commissioners to cause the necessary changes in said rails and roadbeds to be made as soon as practicable; and shall issue certificates of indebtedness against the property, real or personal, of such railway company, which certificates shall bear interest at the rate of 10% per annum until paid, and which, until they are paid, shall remain and be a lien upon the property on or against which they are issued, together with the franchise of said company; and if the certificates are not paid within one year the said Commissioners of this District of Columbia may proceed to sell the property against which they were issued, or so much thereof as may be necessary to pay the amount due, such sale to be first duly advertised daily for one week in some newspaper published in the city of Washington, and to be sold at public auction to the highest bidder: *Provided further*, That after the passage of this act no other rail than that herein mentioned shall be laid by any street railway company in the streets of Washington and Georgetown, and all companies granted franchises or extensions by the Fiftieth Congress shall have extension of one year's time within which to lay their tracks. So much of the charters of the street railway companies of the District of Columbia as is inconsistent with this section is hereby repealed. *Provided further*, That the foregoing requirements as to motive power, rails and roadbeds shall not apply to street railroads outside the city of Georgetown and the boundary limits of the city of Washington; *and Provided*, That the authority hereinbefore granted in each and every particular shall be exercised only with the approval of the Commissioners of said District of Columbia, expressed by resolution of said board. Capt. Fiebeger

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Approved March 2d, 1889.

CORRESPONDENCE.

Mr. Whinery.

S. WHINERY, M. Am. Soc. C. E.—While the subject of these two papers embraces only the relation between street railroad tracks and street pavements, it is rather difficult to separate it from the subject of construction of street railroads in general; but the writer will endeavor, in what he has to say, to confine himself to matter pertinent to the question. It seems necessary to say at the beginning, however, that the interests of the street railroad companies and of municipal authorities in charge of street pavement will be found in the near future to be more nearly identical than is generally recognized at present, and there ought to be harmonious action between them for the following reasons, which will be made the basis of this discussion:

First.—No pavement of any kind can be kept in good and proper condition along the rails of a street railroad unless the track construction is of such a character as to hold the rails rigidly in their position so as to avoid settlement, deflection or oscillation.

Second.—True economy on the part of the street railroad companies requires that their tracks shall be constructed in such a manner that the rails shall have sufficient strength not to deflect or vibrate and that the rails shall be so supported that they will not settle or yield under the loads passing over them.

The truth of the second proposition is forcing itself upon the managers of street railroads. Not a few of them are fully convinced that they cannot afford, as a matter of business, to construct their tracks in any but the most thorough and substantial manner. They have found that cheap and shabby track construction means excessive cost of maintenance of track. When their track is once constructed and a permanent pavement is laid over the street and along their rails, the expense of reaching and repairing the underground structure, raising low joints, tightening joint plates, and replacing the pavement, is so great that a large additional expenditure for a construction that shall be as nearly as possible permanent is more than justified.

Furthermore the wear and tear of cars and motors running over bad tracks is greatly increased. The writer knows of no statistics showing correctly the difference in cost of maintenance of cars and motors operated over poor track and track of the best construction, but from his own observation he believes it amounts to a sum that would pay a very large interest on the difference in cost between good and bad track construction. In view of these facts it is reasonable to expect that owners and managers of street railroads will, in the near future, be more than willing to adopt the very best and most permanent construction for their tracks. In fact, at this time, in many cities the street

railroad companies are voluntarily taking up track that a few years since was regarded as good enough for any street railroad, and replacing it with track of the very best modern construction. Mr. Whinery.

There is, as might be expected, a wide difference of opinion as to what constitutes the best track construction, and many companies are deferring the adoption of improved construction, not so much because they are unwilling to undertake such a construction, but because they are uncertain which of the many plans brought to their attention is the best. It is a fortunate circumstance that in the main the track construction which is best for the street railroad companies is also most favorable for laying and maintaining permanent street pavements along and among the tracks.

Coming now to the first proposition, it is idle to hope to keep street pavements in good condition along street railroad rails unless the rails are rigid and immovable in their place. This is the first condition of success; all other conditions are matters of detail.

In regard to the best section for the top of the rail, the writer does not believe that the section shown in Fig. 3 is the best yet used in this country. The principal objection to it is the sharp edge and unnecessary width of the flange. With a flange of that section, stone or other block pavements cannot be properly maintained along it. Even if the rail is immovable, many of the blocks are liable, upon slight depression, to drop below the edge of the flange as shown by dotted lines *a* in Fig. 27; and having imperfect lateral support, because it is very difficult to fill properly the space between the block and the web of the rail, the pavement soon becomes deranged. If, as is usually the case, the rail is not perfectly rigid and immovable, this danger becomes greatly aggravated. If the rail moves up and down under passing cars, the sharp edge of this flange is likely to engage with the rough surface of the block and to tend to move the block up and down with it.

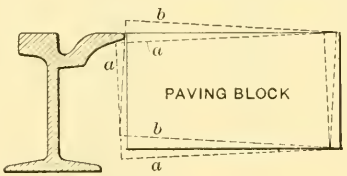

FIG. 27.

If firmly supported on its foundation, the block cannot move downward, but, when raised, particles of sand or street dirt drop under it and it cannot return to its original position. The action is repeated and in time many blocks may be brought to the position shown by the dotted lines *b* in Fig. 27, a condition often seen in brick or stone block pavement along the rails. In the case of sheet asphalt pavements laid directly against the rail, it is hardly possible to compress the asphalt under and against such a flange properly. If the rail vibrates, sand or street dirt will work between the asphalt and the bottom of the flange, and in time the surface of the flange becomes higher than the

Mr. Whinery. rail, which, as will be shown hereafter, is a condition unfavorable to the best service of the pavement. Furthermore, it may be said that the tendency of drivers to keep the wheels of their vehicles on and along the top of the rail is directly as the width of the rail top, and for this reason alone the top of the rail should be made as narrow as practicable.

A few years since Mr. H. J. Stanley, city engineer of Cincinnati, proposed, and the Cincinnati Street Railroad Company adopted, the section shown in Fig. 28 as a standard in that city. There are, in fact, two standard sections used, the only difference being that the rail used on asphalt-paved streets is 6 ins. high, while that used in granite-paved streets is 8 ins. high. In other respects they are identical. The writer believes that this is probably the best section of simple girder rail, from the pavement standpoint, yet adopted for streets. Its advantages are as follows:

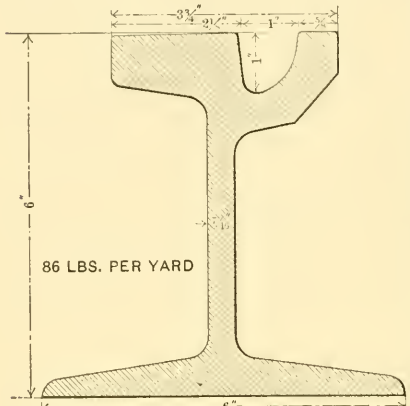

FIG. 28.

The rail is of the grooved pattern, with the flange rising to the same height as the tread. This is the only form of top that ought to be allowed on paved streets. The groove is made no wider than is absolutely necessary to accommodate the wheel flange. It is so narrow that only the narrowest vehicle wheels can possibly drop into it, and it is found in practice that very few wheels, indeed, get into the groove. In fact, with an asphalt pavement laid flush with the top of the rail, the track offers no obstruction whatever to the passage of vehicles, and in driving over the street, one would never know that there was a track in the street, except by seeing the tops of the rails. The sides of both tread and flange are vertical, which obviates the objections to the sharp-edged flange referred to above. This is especially important in the case of asphalt pavements, as a good strong support is secured for the asphalt against the rail. The flange of this rail has abundant strength and mass to withstand the weight and abrasion of travel. The top of the rail, both tread and flange, is joined to the vertical sides by a curve of very short radius, which renders it possible to make a good junction between the edge of the rail and asphalt pavement. Where the top and sides of the rail are joined by a curve of considerable radius, it is obviously impossible to make a good joint between the rail and the asphalt pavement. The top of the rails is as

narrow as it is practicable to make it, consistent with necessary conditions. The strong and wide base and the general sturdy and substantial character of the section commend it to the favor of the track builder as well as to the paver. Mr. Whinery.

In regard to the use of the common T-rail for street railroad track, opinions differ widely. At one time it was regarded as an abomination by paving engineers, municipal officers, and the people, and not without reason, as it was generally used. No one doubts that it offers more strength, stiffness and wearing capacity per square inch of section than any other form of rail in use, and is, therefore, the most economical rail to use from the street railroad company's point o view.

Some recent pavement constructions with this rail have proved very satisfactory, and indicate that where street railroad companies prefer its use, it may be made quite unobjectionable from the pavement

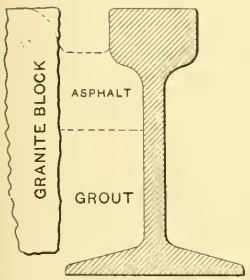

Fig. 29.

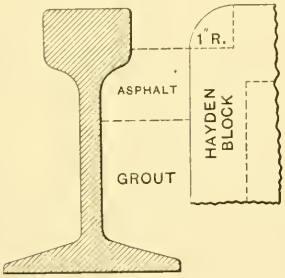

Fig. 30.

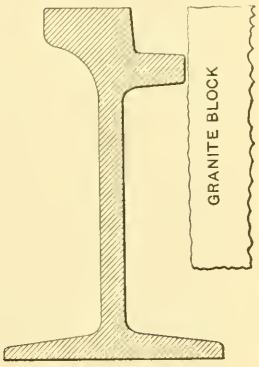

Fig. 31.

standpoint. Fig. 29 shows one construction of this character. The space for the wheel flange is formed by setting granite paving blocks at such a distance inside the rail as to leave sufficient flange space. This space should be made as narrow as possible, and should not exceed $1\frac{1}{8}$ ins. The granite blocks used should be specially dressed so as to present a nearly true face next the rail. They are set against a gauge, a strip of wood $1\frac{1}{2}$ ins. wide resting against the edge of the rail. The cavity between the rail and the blocks is filled to within $2\frac{1}{2}$ ins. of the top with good Portland cement grout, and the space above this is nearly filled with a special asphaltic preparation which renders the joint watertight. The consistency of this asphaltic preparation is such that in warm weather the wheel flange will impress itself into the material, forming a groove of such form and width as will accommodate the flanges. This construction offers far less obstruction to vehicular travel than any of the flanged rails like Fig. 4. Very

Mr. Whinery. few narrow wheels drop into the space between the rail and stone block, and as the groove is shallow, those that do so drop in are extricated without difficulty. In time the exposed corners of the blocks will become worn rounded as shown by the dotted line in Fig. 29, which renders it easier for wheels to leave the groove. There is little tendency of drivers to follow this rail, and consequently little difficulty from wheels getting into the groove.

A similar construction is shown in Fig. 30, where the block used is a brick block known as the Hayden block, with the corner next to the rail molded to a circle of 1 in. radius. Except that the block is not as durable as granite, this construction has proved very satisfactory.

Next to the full-grooved rail, like that previously referred to, this construction offers less obstruction to travel than any other the writer has observed. Where the T-rail is used, its sides should be vertical and the curve joining side and head should have a radius not exceeding $\frac{1}{8}$ in.

None of the rail sections like Figs. 4 and 10 should be tolerated on a paved street. In addition to the other objections their unstable equilibrium when the wheels of a heavy vehicle rest on the flange tends to turn them over and give them a lateral movement, which it is difficult to prevent, and will in time injure the adjoining pavement. A modified form of this section with the construction shown in Fig. 31, ought to give good results. If this construction has ever been used, it has not come to the writer's notice.

It has been generally thought that in laying an asphalt pavement along rails, it is necessary to interpose a line of paving blocks between the asphalt and the rails. It is best to do this where the rail is light and the track construction insecure. No matter what kind of pavement is used, or how it may be laid, it cannot be kept in fair order along the rails of an insecure and shaky track, and the use of the stone blocks lessens, but does not obviate, the difficulty of maintaining the pavement. Besides, people will fail to notice and will tolerate a bad condition of the stone blocks, while they would quickly note and comment on the ragged edge of an asphalt pavement.

Experience has proved that where the track construction is fairly stable, and rails of suitable top section are used, it is better in every way to lay the asphalt surface directly against the rail. It makes a better appearance, offers less obstruction to travel, and can be maintained at less expense than where the stone blocks are used.

It is true that the pavement along the rail will not be as durable as the body of the street, for the line of junction must be a line of weakness to some extent, but the abrasion of the asphalt which occurs will be narrow and can be repaired with more facility and less expense than in the case where stone liners are used.

Where such stone liners are used, the old method of setting them as alternate headers and stretchers should not be followed. A simple line of blocks set end to end along the rail is better, as experience has shown. Where such stone liners are used, their utility will depend largely on the care with which they are set and held in place. Mr. Whinery.

It is not unusual to see street railroad tracks, in which, for the want of suitable foundation and support, the rails have sunk to a depth of from $\frac{1}{2}$ to 2 ins. below the surface of the pavement, and the pavement has become loosened, broken and abraded along its exposed edge. Thoughtless people blame the pavement for the defects, and some cities where the pavements are guaranteed have attempted to hold the paving contractor responsible for the necessary repairs. This would seem to be so obviously unjust as to need no discussion, especially when it is remembered that to repair and adjust the pavement to the sunken track requires a change of grade of the surface of the pavement along the rails. The only adequate remedy in such cases is to reconstruct the track, and raise it to grade before the pavement repairs are attempted, and if the defective track construction has caused the disintegration of the pavement, the railroad company should be held for the cost of repairs.

The depth of the rail is a matter of importance in street pavement, where cross-ties are used. If a shallow rail is used so that stone or brick blocks rest upon, or nearly upon, the top of the cross-ties, the slight motion or tremor of the ties will be communicated to the pavement, and it will, in time, be injured. It is not unusual to see brick pavements between the rails so deranged by this cause that the location of every cross-tie is discernible in the pavement. There should be a space of at least 1 in., and at least 2 ins. is preferable, between the bottom of the paving blocks and the top of the cross-ties. In Cincinnati, where the depth of the granite paving blocks is from 6 to 7 ins., a rail having a depth of 8 ins. has been adopted as the standard for granite-paved streets. This has given excellent results, and the great stiffness of this deep section makes it a good one for the street railroad company also.

In laying asphalt pavement directly against rails, some care is necessary to secure good results. Especial care should be taken to compress the hot asphalt material thoroughly under and around the head and flange of the rail. In cold weather this cannot be properly done without first warming the rail, as otherwise the asphalt will be chilled when it comes in contact with the cold rail and cannot be properly compressed. The surface of the asphalt should be laid even with the top of the rail; if it is laid lower, the latter not only forms an obstruction to travel, but vehicle wheels will follow along the projecting rail and gradually wear a rut there; if it is laid higher than

Mr. Whinery. the top of the rail, the wheels of vehicles, and particularly the tread of broad car wheels, will abrade the edge of the pavement.

If a slight digression may be allowed, the writer would express the opinion that a revolution may be expected in the near future in the present methods of constructing street railroad tracks in paved streets. The coming track is one in which no cross-ties are used, unless that name be applied to small tie-rods placed at intervals to hold the rails from spreading. The rails will be deep and strong, with a base not less than 6 and probably 8 ins. wide. This rail will be laid carefully true to line and surface, on a longitudinal beam of Portland cement concrete, and embedded directly in the concrete foundation and surface of the street pavement. In time probably some form of box girder, with a rail top readily removable and replaceable will take the place of the present rail sections. The girder will have a wide base, and will rest upon a concrete beam, and when once in place will be as permanent as the pavement foundation itself. In at least four cities known to the writer, girder rails laid on a concrete foundation without cross-ties are now in use, and have, so far,

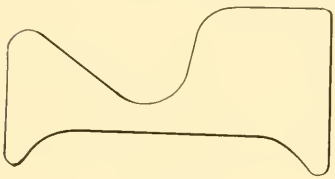

FIG. 32.

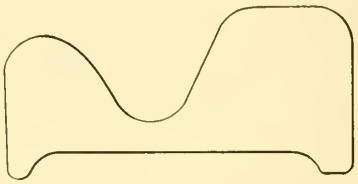

FIG. 33.

given excellent results. A track construction of this character, when perfected, will greatly simplify the problem of paving along or among street car rails.

Mr. Angerer. VICTOR ANGERER, Esq.—The early rails laid on street railways in this country were of a semi-grooved type, similar to the rails used in England, where railways for passenger transportation in city streets received somewhat earlier development, although the street railway was really an American invention Figs. 32, 33 and 34 show such rails laid on some of the first street railway lines in New York and other cities. Wagons and vehicles of all kinds soon commenced to take advantage of the smoother surface presented by these rails than by the street pavements of those times, and tried to follow them. The narrow tires, which partly entered these grooves without getting a flat bearing on any part of them, soon commenced to cut into the soft iron rails, and the deep groove also proved somewhat dangerous to the wheels. This led to the form of rail still known under the name of the "Philadelphia tram rail," first used on the Fifth and Sixth Streets line in that city, which gave a broad flat wagon-way, or tram as it was called,

from which it derived its name. At the same time, the gauge of the track in the city of Philadelphia and in other places where this rail was introduced, was widened, as it had been found that the standard English gauge of 4 ft. 8½ ins. did not allow two horses, which were universally used, to travel abreast between the rails without danger of stepping and slipping on the rails. This type of rail also had some disadvantages from a railway standpoint which were discovered in the earlier forms of rails, in that it showed a tendency to tilt outward under the load, and, further, that the head of the rail was usually covered with mud and dust, without any possibility of the wheels themselves cleaning this accumulation away. The usual T-rails on steam railroads and lines outside of city streets did not show such a tendency, which led to the introduction of a rail approximating the T-rail and adaptable for city streets, and to the usual construction of a flat rail on wooden stringers. This approximation of the T-rail, really a T-rail lowered so that the head came down on the base without the intervention of any web, has since been known as the center-

Mr. Angerer.

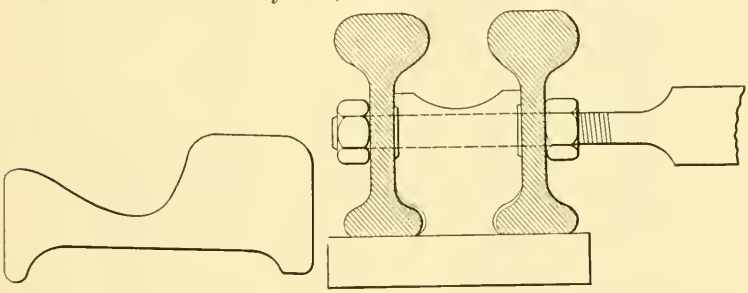

FIG. 34. FIG. 35.

bearing rail, it giving, as the name indicates, a central bearing of the wheel on the rail, and of the rail on the stringer, *i. e.*, a better distribution of the load on its supports. Further advantages claimed for it were that the head cleaned itself from mud and ice, and it gave two lines of spikes instead of one as on the other rails, and reversibility, that is, when one side has worn away from the action of the wheels, it could be turned round to give further use, although advantage was rarely taken of the last feature. Incidentally, it also did away with at least some of the necessity for widening the gauge, as the difference between the metallic surfaces was widened by the difference of the width of the usual tram on the other rails and the small spiking flange on the center-bearing rail.

This, in short, is the writer's understanding of the development of the top surfaces of street railway rails in this country. The center-bearing rail undoubtedly presented many advantages to the railway company, not the least of which was the fact that it was much more difficult for wagons to follow this rail than the former shapes, although

Mr. Angerer. they still continued, at least they attempted, to follow it wherever its surface held out an advantage over the surface of the pavement. The objections to this form of rail, its bad influence on the pavement through the obstructions it offers to vehicular traffic, are well known. The unsightliness and disadvantages of these rails became more and more apparent as the pavements and the methods of laying the pavements improved. It was just ten years ago that the public in various places, and especially in New York City, waged war against the center-bearing rail, which ultimately led to its condemnation, although there is still a large amount of center-bearing rail in the streets of the city of New York, while in other places it has almost disappeared.

It was then that the matter of the use of a rail with narrow grooves similar to the rails used in England and on the European continent was largely advocated, and some French systems particularly were taken as models. These are illustrated in Figs. 35 and 36. Much was written and said at that time as to the practicability of the use of such

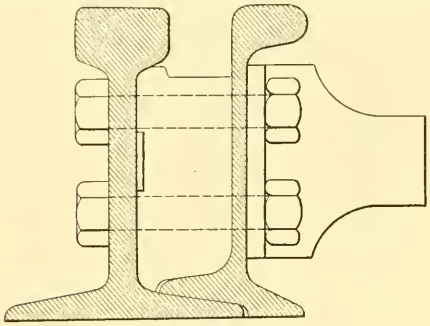

FIG. 36.

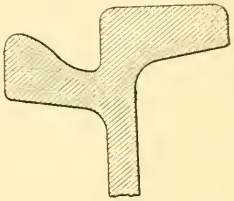

FIG. 37.

a rail in American cities. By the grooved rail at that time was always understood what is now called a rail with a flush or full groove, that is, the guard or tram part of the same height as the head. The main objection raised against these rails was, at that time at least, that only in the very rare cases of the principal streets in the principal cities was the pavement in such condition that drivers would not wish to follow the smooth surfaces of the rails, and as there was nothing to guide them on the flat and narrow surface of the full-grooved rail, they would continually slide off on one side or the other, and soon cut ruts alongside of the rail; and, as a second objection, that the grooves could not be kept free from dirt or ice in winter except at very great expense, due to the wagons running on the track and sweeping the dirt into the grooves, and on account of the greater severity of the climate than in those parts of Europe where full-grooved rails are in more universal use. Both assertions were proved to be facts by pieces of track laid with flush-grooved rails in several cities, some with rails directly im-

ported from England, and some with similar rails rolled in this country. It was then that the half-grooved rails were suggested, and the so-called Richards rail of that type and some other rails were laid extensively throughout the following years in various cities, and in fact the rails laid on the Broadway and Third Avenue cable roads (Figs. 2 and 5) are representatives of this type of rail. The idea was that the tram or guard part, not coming up to the full height of the head, would give some guidance to the wagon wheels, and, further, that the reduced depth of the groove would allow it to clean itself more readily by the action of the wheel flanges. Both objects were defeated, at least to some extent, first, in that the surface presented to the wagon wheels was too small and therefore quickly worn away, and consequently wear was thrown on the adjoining paving stones by the wider tires, and, further, that the groove did not clean itself, especially from ice and snow in winter, owing more particularly to the lines of the sides of the groove, which were too steep. Some other rails were designed with grooves of different shapes, approximating the half groove, but with rounding sides, as in Fig. 37. These cleared themselves of dirt to some extent, but not sufficiently, and they further developed the curious difficulty that even on very slight curves the flanges of the wheels showed a tendency to run up on top of the rounded side and cause the car to leave the track. This, however, could have been obviated by making the groove somewhat wider. All these later rails were of the girder type, the girder rails having in the meantime largely replaced the old flat rails on stringers, which, however, had nothing to do with the top surface. Mr. Angerer.

It is but natural to ask why a full-grooved rail should not be used in this country as it is in London, Paris and other foreign cities, since American pavements have attained the same degree of excellence, and the principal objection is thereby removed. The conditions, however, are different. In the cities mentioned, street railways are, as a rule, banished from narrow streets. They are generally given the privilege only on wide streets where there is plenty of room for other traffic, and, besides, the streets are not as much obstructed by teams standing along the curb loading and unloading in front of warehouses and stores, as they are in great commercial cities in this country, all this work being done more or less in back streets and large court yards, while here the street railway track and very little room on both sides of it offers very often the only unobstructed passage-way for vehicles and wagons in the street. Many of the wide avenues in New York are obstructed by elevated railroad posts, cut up into three strips, so to speak; the two nearest to the curbs are rarely clear for vehicular traffic, and the central one is occupied by two tracks on which the wagons are more or less compelled to run. On other avenues in New York and in other cities there are four railway tracks running parallel, occupying practically

Mr. Angerer. the entire width of even the wide streets. The drivers, even if they wanted to, cannot, in most cases, avoid these tracks. They do not wish to overlap them, as that brings the smooth surfaces of the rails under their horses' hoofs, causing them to slip, and, in consequence, if for no other reason, they will follow the track as much as the track will permit. If a rail with a flush top surface like the English grooved rails is used, two ruts alongside of each rail will soon appear. If a rail is used that gives a guide to the wagon wheels, and at the same time gives a width of surface for the wheels to run on equal to the most prevalent width of tire, these ruts will be avoided, and the only marked lines of wear on the pavement will be on both sides of the track, produced by those wagons which are of wider gauge than the track. It is the writer's opinion that the last-named wear on the pavement is less serious than the ruts alongside the flush-grooved rail. It may be said that in Washington the flush-grooved rail has come into extensive and successful use, but the conditions there are markedly different from those of commercial and industrial cities, the streets are wide and unobstructed, and the traffic light. It will also be observed that the flanges on the car wheels used in Washington are much smaller than the flanges used elsewhere; the narrow groove of the rails will not permit larger flanges. The railway companies, especially those using mechanical traction, object to these small wheel flanges, not as a matter of economy, because the wheels wear out faster, but as a matter of safety.

Street railways now extend into the suburbs of the cities, and the suburban traffic has to be brought into the heart of the cities. The cars which run on the suburban lines also have to run on the tracks in the city proper, but in these suburbs the speed demanded is much greater, and the greater speed demands larger flanges on the wheels for safety. The rail of the Metropolitan Traction Company, Fig. 3, gives the necessary width and depth of groove for such flanges, but it will be seen that it will allow the narrow tires of light buggies to drop quite deep in the groove, below the part of the side rounded off, so that turning out must throw quite a heavy strain on the light wheels. Slightly wider tires up to about $1\frac{1}{2}$ ins. in width sink into the groove, when new, just far enough to be guided, but they run only on one edge, and the tendency would be to wear the groove wider and the sides steeper. Wide tires, on account of the tram being carried to a level with the head, have no guide, and are free to slide off to both sides, and produce the wear on the pavement mentioned. The extra width of the tram for this reason does no particular good. If the tram was lowered, say at least $\frac{1}{4}$ in. below the head, it would accomplish its object in guiding and providing a surface for the wagons. This lowering would also permit the side of the groove to be made still more flaring, thereby facilitating the turning out of the very narrow tires and

increasing the chances of the groove clearing itself from dirt and ice; it does not do it now, in fact it is said that some difficulty has been experienced with cars running off on account of ice in the groove. Mr. Angerer.

Without going into the details of increased frictional and electrical resistance, it must be admitted that a tolerably clean rail is essential for the practical operation of surface railways, and unless the rail is so shaped that there are good chances of it being kept clean by the action of the wheels themselves, it will have to be kept clean by other means. Scrapers and brushes attached to the car necessarily have to be of a somewhat flexible nature so as not to catch in irregularities or at joints, and are therefore not sure to remove packed and frozen dirt and ice. The use of salt would, of course, help this somewhat, but this is universally objected to by the authorities and the public. Men with hand scrapers to walk along the track and clean the groove in accordance with European practice would have to be resorted to, but this would be found hardly practicable, aside from the question of expense, in some of our busy streets. In view of the desirability of a clean rail head, the bevel on the back of the head of the rail shown in Fig. 10, which has been called one of the vices of this rail, would be one of its virtues from a railway standpoint, and the writer cannot understand the serious objection raised against it. This beveled extension of the head, however, has been put on not solely for the purpose of allowing the wheels to clean off the dirt towards the outside, but also to provide for a wider tread on the wheel, without having it strike some projecting paving stone. In the writer's opinion, wider treads on the wheels are quite certain to become one of the requirements of the street railways, owing to the suburban lines above referred to, and, further, to lessen the severity of wear of the heavy motor cars on frogs and switches. If the life of the latter could thereby be lengthened, and the disturbance of the pavement around them, due to their comparatively frequent replacements, be minimized, it would be one advantage gained from the paving side of the question. With this bevel added on the outside of the head of the rail of the Metropolitan Traction Company, but with the tram lowered, as shown in Fig. 38, and the corner at the gauge line of this rail rounded off a little more,

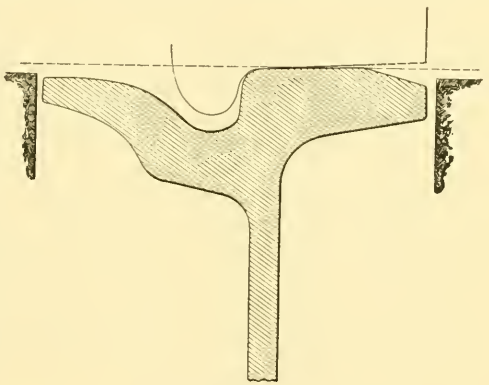

Fig. 38.

Mr. Angerer. the resulting section might prove the right form for the best paved streets. The writer's plan would be to carry the pavement not quite up to the level of the head, which would give a practically even surface all over the street with very little obstruction to the crossing of vehicles by the slightly projecting heads, and at the same time provide for some of the necessities pointed out in regard to the wagon traffic running longitudinally with the tracks. Where the pavement is not laid with such nicety as to level, and is not of such a character that it would keep to such level, the writer is inclined to think that a top similar to the old Philadelphia tram rail is probably the most useful. On curves, especially on sharp curves, a guard rail with the guard projecting above the head with a groove sufficiently wide to allow for the skewed position of the wheels will, of course, have to be used to insure the safety of the cars on curves.

As to the type of rail, it is hardly probable a railway company can be found to-day which is willing to put down the old flat rail on stringers in preference to the girder type, except for repairs in some old tracks. The more permanent and solid character of the girder rail construction also makes it more desirable in its relation to the pavement, provided, of course, as pointed out by Mr. North, that the spaces underneath the head and the tram are properly filled with some material before paving, when stones are used for the entire pavement, or alongside of the rail in asphalt pavements. As to the height of the girder rails, or, in other words, the depth to which the ties should be buried beneath the surface of the street, it certainly should be as much as 9 ins. where blocks are used. In asphalt pavements where the asphalt is carried to the rail, and in brick or similar pavements, 7 ins. or even 6 ins. might answer. Mr. North has well pointed out the relative value of the different kinds of pavement when laid alongside of a rail, and how they should be laid.

As to the suggestion of an iron plate laid alongside of the rail, it would only prevent the ruts from forming if it was made very wide, so that the wagons would not be apt to leave it; but such a wide metal surface in the street would in itself be objectionable, would be difficult to keep down, and would quickly wear out if made as thin as described.

As to the rails for steam railway cars and locomotives in city streets, the devices described are certainly among the best, but on account of the absolutely necessary depth and width of the grooves, it is doubtful whether any rail for this purpose can be devised which would not be objectionable and destructive to the pavement in city streets. Fortunately, the steam railway track in paved city streets is on the wane.

Mr. Price. W. G. Price, M. Am. Soc. C. E.—Since the introduction of electric traction there has been a great increase in the number of flat wheels

produced on street cars. This is due to the increased speed at which the cars are run, and to the increase of weight on each wheel, which has been more than doubled. When light trail cars are hauled by electric motor cars it is seldom that a flat wheel is made on the trailer, and but few flat wheels are produced on the light cable cars. The wheel is flattened by sliding it on a dry or sanded rail. When the bearing surface of the rail is level, and the tread of the wheel is conical or beveled, as in Fig. 39, the contact between the wheel and the rail is a mere point; when the wheel slides the metal of the wheel is heated and softened at this point and is easily abraded so as to produce a flat

Mr. Price.

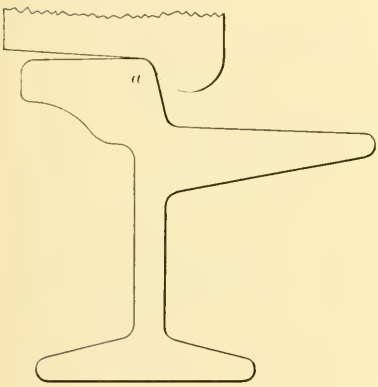

Fig. 39.

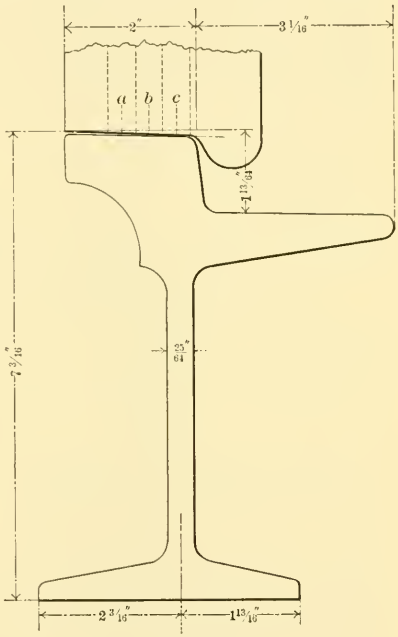

Fig. 40.

spot. By changing the form of the rail to that shown in Fig. 40, which is beveled to fit the conical wheel tread, a much larger surface of the wheel will be in contact with the rail, and it will require a much greater weight to produce abrasion when it slides.

This form of rail has been adopted by the Chicago City Railway Company, and is proving to be very satisfactory. Old rails are found to be worn to this shape, which has been done at the expense of much abnormal wear to the wheels. When the rail is beveled, the wheels retain the beveled tread, which is necessary to enable a lagging wheel to catch up without slipping on a straight track. The bevel of the wheel

Mr. Price. is of very little benefit on street railway curves, owing to their short radius. Figs. 40 and 41 show sections of rails now in use on the State Street cable line, the height of the head being $1\frac{3}{16}$ ins. It is beveled to conform to the bevel of the car wheel for two-thirds of its width from the gauge line across the head. There is probably a slight slipping of the wheels on the rails due to the unequal diameters of the wheel at the points of contact. The point *c* will travel faster than than *b*, and *a* will travel slower than *b*. The waste of power due to this slipping is very slight, for considering the coefficient of friction as 0.15, it will be found that for a load of 1 ton at a speed of 10 miles per hour, the energy consumed to produce this slipping is 0.0104 H.-P. The experience of the Chicago City Railway Company has been that the beveled rail saves wear of both rails and wheels, increasing their life by about 35 per cent. Fig. 42 shows a section of a new and old car

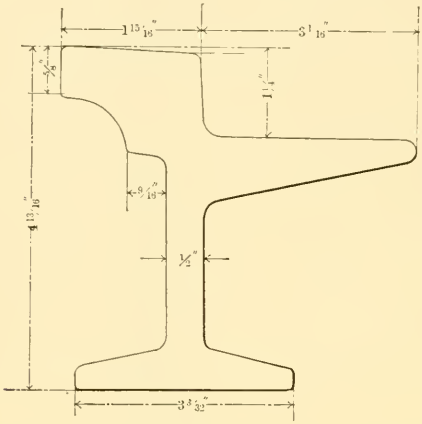

FIG. 41.

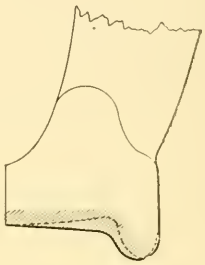

FIG 42.

wheel, which illustrates clearly the manner in which the tread will wear if used on a rail with no bevel.

The cast-welded rail joint is a great improvement over old methods, as it reduces largely the repairs required to track and cars, greatly increases the life of the rail, and increases the number of passengers carried, as the cars run with much less noise and vibration. A lighter rail can also be used.

Mr. M. K. Bowen, Superintendent of the Chicago City Railway Company, has made the following statements:*

"Seventeen thousand joints were put in during the year 1895, and of these only 154 joints were lost. The joint in comparative tests has been shown to be far stronger than the rail itself, and such breakages as have occurred were due to a flaw in the metal. The metal cast around the joint has eight times the cross-section area of the rail. Hence,

* In a paper presented to the American Street Railway Association, October 20th, 1896.

considering steel as four times as strong as cast iron, the joint is twice as strong as the rail. It has been found in some cases where this joint was used at crossings with other tracks, that the tracks were apt to be pulled out of shape through the changes of temperature. To overcome this, the joint nearest the crossing should be anchored in a substantial manner. The method of making the joint is as follows: The rails at the joint are scraped and brightened, a cast-iron mold is placed around the joint, making a tight fit. Into this the molten iron, 25% scrap, 25% soft, and 50% hard silicon pig iron, is poured; the metal in contact with the mold begins to cool and form a crust while the interior remains molten. This crust continues to cool, and at the same time contracts, forcing the molten metal strongly toward the center, which makes a solid and rigid joint. The top, or bearing part of the ball of the rail is afterwards filed off perfectly level, so that it is very difficult to detect a joint by riding over it or looking for it. Upon breaking a joint which has been cast-welded, three spots will usually be found where amalgamation has taken place between the rail and cast portion, one on each side of the web of the rail and the other on the bottom. These spots are from 1½ to 2 ins. in diameter. There has been some discussion as to its being a bond for carrying electric current. I cannot recommend it with certainty, as there are occasional joints which I have taken off where no amalgamation has taken place whatsoever, thus destroying the effect as a bond of all joints in that line of track. To overcome this difficulty I have adopted the plan of bonding all joints. However, further experiments and care in the casting of joints may develop their efficiency as a bond." Mr. Price.

The question as to what condition a track should be allowed to deteriorate before beginning repairs is a very important one. There is a point of time in the life of the track at which money expended in repairs will be most efficient. Mr. Bowen says on this subject:

"The task of solving this question was brought before me not long ago concerning the State Street cable track, which had reached a deplorable condition. I had run over the line a car weighing 8 665 lbs., attached behind a grip-car by means of a recording spring balance called a dynamometer. This test car was then run over a track newly made at the same speed as over the old line; the dynamometer showed that it took 13.75 lbs. more pull per ton to haul cars over the old line that over the new. The average speed of cars on this street is 12 miles per hour. The excess horse-power required to haul 1 ton was 0.44, and the excess cost of hauling 1 ton one hour was $0.0088. The number of tons hauled 1 mile per year on this track was 45 147 537, and the time required to haul 1 ton 1 mile was five minutes; and 45 147 537 tons hauled at a given speed for five minutes is equal in work done to 3 762 295 tons hauled at the same speed for one hour; 3 762 295 multiplied by $0.0088 equals $33 108, which is the excess cost per year for hauling cars on account of bad track. It is estimated that the new track with cast joints will last twelve years, and as there will be no low joints the drawbar pull will not increase much until the rail is worn down sufficiently to allow the wheel to run on the flange, so the annual saving will be nearly $33 108, during the life of the rail, and the total saving will be $397 276, which in twelve years will pay principal and interest on $293 444, which is the amount we could profitably expend in repairs. The actual cost of rebuilding this track was $61 670."

Mr. Price. It is evident that if this track had been repaired at a much earlier date, a considerable amount of money that was used in buying coal and repairing rolling stock could have been added to the dividends.

Mr. Jennings. W. T. JENNINGS, M. Am. Soc. C. E.—Toronto has now about 80 miles of track, yielding $64 000 per annum for track mileage rental.

A clause in the condition of the sale of the street railway franchise, dated May 5th, 1891, reads as follows:

"The city will construct, reconstruct and maintain in repair the street railway portion of the roadways, viz., for double track 16 ft. 6 ins., and for single track 8 ft 8 ins., on all streets traversed by the railway system, but not the tracks and substructure required for the said railways."

The railway company pays to the city treasury the sum of $800 per annum per mile of single track, sidings and turn-outs not being counted as track mileage, and also pays the following percentages:

On gross receipts up to $1 000 000 per annum, 8%
" " " between $1 000 000 and $1 500 000 per annum, 10%
" " " " $1 500 000 and $2 000 000, 12%
" " " " $2 000 000 and $3 000 000, 15%
over $3 000 000..... 20%

The annual receipts in 1886 were about $1 000 000.

The company is to maintain the track in a state of thorough efficiency, and remove, renew or replace it, as the city engineer may direct. The specifications provide that cars are not to be overcrowded; a comfortable number of passengers for each class of cars is to be determined by the city engineer and approved by the city counsel. Cars are to have right of way, and vehicles or persons are not to obstruct or delay their operation.

Mr. Cushing. E. B. CUSHING, M. Am. Soc. C. E.—In connection with the subject of more permanent methods in street railway construction, and the consequent less frequent disturbance of pavements, it would be profitable to consider the preservation of timber used in such construction. There is quite a variation in the life of ties of the same kind of timber. In an instance which came under the writer's notice, the best of a lot of ties used in construction lasted nearly twice as long as those which first failed, although of the same timber. When the wood began to rot, some part of the line was thus disturbed yearly for tie renewals. Unless the conditions are such that the beds of the ties are generally dry, those methods of preservation in which mineral salts are used will probably not be satisfactory, as such salts are easily soluble in water. The use of dead oil of coal tar, creosote, would without doubt be economical. Sap pine, *Pinus mitis*, suitable for creosoting, can be purchased in southern markets at from $1 to $4 less per 1 000 ft. B. M. than the heart pine. Ties of this timber treated with 12 to 14 lbs. dead oil per cubic foot could probably be obtained for 60 to 80 cents each, f. o. b., at any creosote works situated convenient to timber

supply. Such ties would last from 18 to 25 years. While it is desirable to have timber treated at regular creosoting works in order that the best results be obtained, the writer believes that should transportation charges render this impracticable, a street railway company having extensive mileage could construct at its power house, at reasonable cost, an apparatus for boiling seasoned timber in the oil, and that the interest on the cost of such a plant would be more than saved in the annual timber renewals. Creosote does not permeate to the center of the timber, but forms a black ring an inch or so in thickness, thus excluding the elements of decay. Where it becomes necessary to trim or cut the timber after treatment, it is important to apply hot creosote with a brush to the place cut, and where track is regauged, the hot liquid should be poured into old spike holes. The neglect of this simple matter has caused failure of creosoted timber that would otherwise have lasted many years. Mr. Cushing.

Horace Andrews, M. Am. Soc. C. E.—In Albany the side-bearing rail was prescribed by the common council in 1885, and as the old center-bearing rails wore out, they were replaced by side-bearing rails of the general shape, on the wearing surface, of Fig. 4. A 9-in. girder rail, similar to Fig. 4 in all respects, is the latest pattern, adopted after numerous trials of different forms. On asphalt-paved streets granite blocks were laid, alternate headers and stretchers, and the general surface of the asphalt between the rails was kept at the level of the top of the rail. Owing, as the writer believes, to the insufficient and improper foundation of the rails, the blocks were shaken loose at many places, and the railway company has taken them up. In replacing the asphalt its surface has been kept level with the inside flange of the rail, thus increasing the difficulty of crossing the track. Whether ruts will form in the asphalt adjacent to the rails remains to be seen. Last summer brick pavement was laid on an avenue where there was about 6 500 ft. of double track. The writer urged the railway company to dispense with wooden ties or sleepers, instancing the practice in Toronto, where it is stated the result from laying the rails directly on Portland cement concrete has been quite satisfactory. The company believed its interests would be secured by the use of wooden ties, however, and used these, spaced about 2 ft. between centers. Fortunately in this instance, the first in the city, concrete was laid below the ties to a depth of 6 ins., and the railway company filled between and over the ties to within about 6 ins. of the surface of the pavement, with concrete. Molded bricks were used to fit under the flanges of the rail, a different pattern being required on each side. Mr. Andrews.

In Albany the expense of new pavements may be assessed "among all the houses and lots, vacant lots and franchises intended to be benefited." Until 1891 the expense to be borne by the street railways was

Mr. Andrews. defined by law as that for work, labor and materials required to pave between the rails at each track, and no more. This has been amended so as to leave the assessment discretionary, as above noted.

Large assessments have been paid by the railway company, as almost every street where tracks are laid has been repaved with granite, asphalt or brick within the past ten years. The benefit accruing to the railway company from the repaving of a street may appear slight, but, when a side-bearing rail is employed, a good pavement tends to divert the traffic from the rails, which are otherwise the pleasantest and most used part of the street, and thus the company gains an incidental benefit.

There are four matters suggested by the papers on which further information is to be desired:

First.—Can the form of rail shown in Fig. 3 be used in connection with Fig. 4 with car wheels of ordinary pattern ?

Second.—If a concrete base is to support the rail, without ties, is not a 6-in. girder rail with a wide bottom flange better than a 9-in. girder rail, especially with brick or asphalt pavements?

Third.—With a good block or brick pavement cannot the rails be preserved to correct gauge without the use of cross-rods at frequent intervals ? The writer has seen a brick-paved street where these rods were entirely omitted, yet the gauge was well maintained. The rods are much in the way when paving with blocks or brick. With bricks especially they interfere sadly with correct alignment.

Fourth.—What is the best position for the wires making the electric bond between rails ? It would seem easier to pave between the rails with the bond on the flange and not on the web of the rail.

Mr. Tratman. E. E. Russell Tratman, Assoc. M. Am. Soc. C. E.—It is unfortunate that there should exist such inharmonious relations between the street railway companies and the municipal authorities, by which the public has to suffer. The streets are laid out and maintained for the accommodation of the public, and the street railway is simply allowed to use them in affording better accommodation and more rapid means of transportation for those who care to pay for such increased facilities. It has, of course, certain rights, including a right of way for its cars, but it has no right to interfere with the use of the street by the public at large. If the company's charter requires the company to do its share of the paving, means should be taken to enforce compliance with this requirement. If there is no such provision, then it is the duty of the city to see that the street is properly paved and maintained. The experience at Washington has shown that railway companies can be held in control in respect to this matter, and there is no good reason why this should not be done in cities having the ordinary form of municipal government. One actual reason, but not a good one, is the bad system of organization of such government

in many cities, and its control by politicians for party and personal interests rather than public interests. Without good governing bodies it is useless to expect good government, good streets or good administration of affairs. Mr. Tratman.

As to the special tracks for steam railway traffic on city streets, while there may be cases where such construction is still necessary, it should be emphatically stated that at this time a paved street is no place for a steam railway to occupy.

O. H. Tripp, Assoc. M. Am. Soc. C. E.—In 1892 a street railway company began operations in Rockland, Me., and received permission to use a T-rail. The main street through the center of the town is paved with granite blocks on gravel with gravel joints, and for some distance to the north of this paving the space between the rails and 1½ ft. outside is also paved. The city paid for the blocks, and the company did the work. Through the portion of the street paved, the track is in the center of the street; where the track is on the side, no paving whatever was done. The track is of 50-lb. T-rails, and where there is a pavement it is on cast-iron chairs to admit the depth of the paving blocks. The ties are about 5 ins. deep by 6 ins. wide and 7 ft. long. The consequences of this construction are just what any one familiar with such tracks would readily foresee. The groove inside the rail is such that there is constant danger of crippling the wheels of any light carriage caught in it, unless great care is taken, and in many places the outside rut is nearly as bad. Several lessons may be learned from such an experiment. Among them, speaking more especially of small towns, would seem to be: Mr. Tripp.

First.—The advice of an expert should be asked before granting any right of way, and the whole structure, by constant, careful inspection, should be made to correspond to his instructions.

Second.—The company should be rigidly bound to keep the part of the street occupied by it in complete repair at all times and under all circumstances, so as to offer the least possible interference with usual traffic of the street.

Edwin Mitchell, Assoc. M. Am. Soc. C. E.—The ideally perfect railway track on a paved street would be one that does not interfere with other traffic on the street, while properly fulfilling its purpose as a railway. To approach this perfection two conditions must be fulfilled; the rail must make the least possible break in the evenness of the street surface, and the construction and material must be of such strength and durability as to cause the least possible necessity for repairs. That there is little track which begins to approach these conditions is not surprising, considering the quick growth of rapid transit systems. Ten years ago nearly all street cars were light horse cars drawn at a rate seldom exceeding six miles an hour. Now there are electric cars with as much as 5 tons on a single axle running at Mr. Mitchell.

Mr. Mitchell. rates of 15 and even 20 miles an hour. This development, of course, could not be foreseen in the first days of rapid transit in cities, and there were very insufficient provisions in regard to methods of construction in nearly all of the franchises first given. That many of the franchises granted in more recent years are little better in their provisions in regard to manner of construction and maintenance of the streets is a fact reflecting great discredit on the bodies disposing of such valuable privileges. The majority of the recent franchises have contained provisions of greater or less stringency in regard to maintenance of the paving about their tracks. There are instances where an enlightened management has been alive to the fact that their own interests consisted in the best possible construction, but the attainment of good construction must usually be accomplished by municipal regulations.

It is interesting, in this connection, to see what has been accomplished in those cities which have the most satisfactory street railway

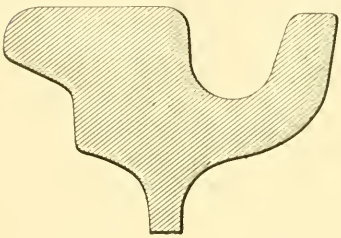

FIG. 43.

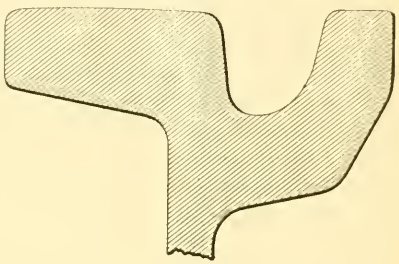

FIG. 44.

tracks. In Washington street railway building has proceeded under much stricter regulations and with better results as regard track and foundation than in any other city of which the writer has knowledge. Fig. 43 shows the head of the rail, adopted by the Washington and Georgetown Railroad Company, now the Capital Traction Company, for their cable lines. This is an 80-lb. rail, 6 ins. high, with a 6-in. base. Fig. 44 shows the head of the rail adopted by the Metropolitan Railroad Company for their underground electric lines. This is an 83-lb. rail, $6\frac{3}{4}$ ins. high, with a $4\frac{3}{4}$-in. base. The Columbia cable road has a rail almost the same as that of the Capital Traction Company. It can readily be seen that no ordinary wheel tires can slip into these grooves. The roads mentioned, having a central conduit, cannot make use of cross-tie construction. Fig. 45 is a cross-section of the road-bed of the Capital Traction Company. The cross-section of the Columbia Railway Company is similar, except in the paving. The latter company, however, has the yokes spaced 5 ft. apart, while the

other lines have 4½-ft. intervals. The underground electric lines differ in having a shallower conduit and yoke. In these roads there is no material to decay, and with a perfect joint they would be as near everlasting as could be devised. Mr. Mitchell.

The joints of the Capital Traction Company are light four-bolt angle bars, which have sunk and given a great deal of trouble. A number of cast-welded joints have been put in during the past year as an experiment. The tracks of the Columbia and of the Metropolitan roads, which have been built more recently, have heavy six-bolt angle-bar joints, and they have given little trouble, as yet. From an extensive experience with steam railroad track, however, the writer believes that there is no form of splice joint supporting only the head of the rail which will maintain a good surface for any great length of time; and he believes this to be even more true of street railway track where the joints are out of sight, and constant vigilance cannot be exercised for loose bolts.

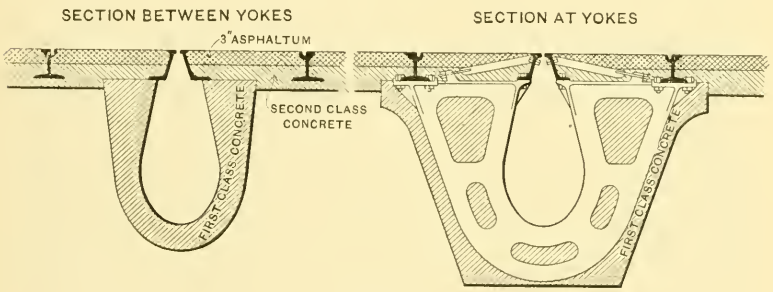

FIG. 15.

On the lines of the Capital Traction Company and the Metropolitan Railroad Company, the asphalt has been laid up to the rails and is cracked and broken in many places. On the Columbia Railway vitrified brick have been used between the rails with a toothing course of brick on the outside, and the adjoining asphalt is well keyed and is preserved in good condition. The horse-car lines in Washington have a grooved rail, as ordained by Congress, laid on cross-ties with a cobble or block pavement between the rails.

For a track with a firm pavement and pavement foundation on both sides of its rails and where all portions of it cannot be examined at frequent intervals and loose ties secured and low places raised by tamping, a longitudinal system of supports giving a continuous bearing seems to the writer to be the logical method of construction. One advantage of this in laying the track is that it is necessary to excavate to the full depth of the track foundation for only a narrow space beneath the rails. In Detroit, where a new railway was put down in a well-paved street, only sufficient pavement was taken up to excavate a

Mr. Mitchell. trench for the concrete stringers and to put the tie-rods in place. All perishable material should be avoided. The only instances where such track construction has been adopted—a rail laid directly on a longitudinal concrete support—of which the writer can obtain knowledge, are in the cities of Montreal, Toronto, Detroit, Minneapolis and St. Paul, and in all of these places the method seems to have given a satisfactory track.

From a study of what has been accomplished so far, the best track for rapid transit railways in a paved street would seem to be a rail similar to those in use in Washington, made 8 ins. high, however, if granite or asphalt block paving is used, laid on a concrete stringer or a flat metallic stringer, bedded in concrete, with tie-rods at 6-ft. intervals, with a strong base-supporting joint, preferably a welded joint if the difficulty with broken rails is not too great. If the track is in an asphalt-paved street, toothing courses of brick will make the smoothest and best bond for the asphalt at the sides of the rail.

Mr. Plimpton. ARTHUR L. PLIMPTON, M. Am. Soc. C. E.—In speaking of the condition of things where the municipality keeps the whole pavement in repair and collects from the company the cost of the latter's part between tracks, Mr. Owen says: "This might work satisfactorily if one point did not come up to create trouble. It is the one point that is going to make endless friction and is the unconsidered element, viz., the repairing and renewing of the track itself." The author here certainly touches upon what is already proving to be and will be more and more in the near future the greatest difficulty of all, for up to the present time the best street railroad track known on which a large number of cars are operated will give out long before the pavement needs renewing, provided the latter consists of granite blocks laid on a concrete foundation at the time the track was built. Mr. Owen refers to the practice of maintenance of track on steam railroads, and does not seem to appreciate the real reason why similar methods are not followed on even the best managed street railroads, but the writer will state that it is a vastly different matter keeping track in good condition on a street railroad from what it is on a steam road, where the location is owned and entirely under the control of the company, and every bolt and nut is in sight. A steam railroad roadmaster told the writer that he let the street crossings go as long as possible without repairs, as it was so difficult to get at the tracks at such places. On the street railroad it is all like the street crossing of the steam road, it is all in the street. It is absolutely impossible to do anything in the way of setting up bolts to a track as now generally built without the removal of and therefore permanent injury to the pavement. Hence the early attempts that were made to introduce boxes at the joints, which would allow access to the bolts and nuts by removal of an iron cover in the surface of the street, but these did not prove to be satisfactory and have been

given up. In short, the difficulty and expense of watching and keeping the fastenings tightened up is so great that no attempt is really made to do it until the track has fallen into bad shape. Mr. Plimpton.

Street railroad companies have by no means been idle, but have been striving all the time to build a track in such manner as to require practically no repairs; notably, such improvements as making frogs and switches of solid construction instead of in separate parts bolted together, making the frog centers and the parts of the switches that would ordinarily wear out first of specially hardened steel, making a steam railroad crossing one solid structure throughout, laying the track on a concrete foundation, making the rails themselves of harder steel, the use of 60-ft. rails instead of 30-ft., and the welding of the joints of the track itself. These are all in the line of a longer life for the track and really seem to be the only direction in which to work to help the problem.

With regard to the ideal track on Beacon Street in Brookline, where the tracks are on a reservation 20 ft. wide all grassed over, it has proved to be a great mistake, as was predicted in advance, to try to raise grass on a railroad track, for not only is it impossible to maintain the track at a good surface owing to the loam working down into the gravel bed, but the life of the ties is shortened and in winter the freezing of the loam causes an upheaval of the surface so great in places that it has to be trimmed off in order to allow the cars to pass over without scraping, thus defeating the very object of having it a grass reservation.

In the writer's judgment, if, after being properly tamped, the track should be covered with pebbles or beach gravel to a depth of 1 or 2 ins. over the ties, and then if the space between the tracks and the space on each side between the reservation and the roadway be made nicely kept grass areas, even if they should be not more than 2 ft. wide, surely the railroad company could maintain the tracks in much better condition, and their appearance would be better than the present so-called grassed area with its numerous bare spots. Setting aside the exact way the tracks shall be built, the idea of a reservation is in itself a most excellent one, as it affords an opportunity to run cars at much greater speed with far less liability to accident.

G. L. Wilson, M. Am. Soc. C. E.—In 1895 the City of St. Paul repaved several streets upon which there were street car tracks with sheet asphalt, the street car company being obliged by the common council under the terms of its charter to lay the same pavement on the space occupied by its tracks. This was done with the ordinary track construction, the rails laid on wooden ties, to which they were spiked, and, after lining and surfacing the track, a 6-in. concrete foundation was put in around and between the ties and the paving laid, leaving the track simply imbedded in the paving, but with no solid foundation under the ties. With the heavy electric cars now Mr. Wilson.

Mr. Wilson. operated it was found that the vibration of the track under traffic, especially with an asphalt pavement, was sufficient to destroy the adjacent surface rapidly. In 1896 an attempt was made by the Twin City Rapid Transit Company, which operates the street railways in both St. Paul and Minneapolis, to put down a permanent and solid track and then to have the pavement laid so as to make a solid construction, as nearly as might be. With this object in view, after investigating the methods in use in Toronto and Montreal, it was decided to adopt an 80-lb. rail of the section recommended by the rail committee of the American Society of Civil Engineers, in 60-ft. lengths with Falk cast joints and connected with tie-rods $\frac{7}{8}$ x 2 ins., spaced 12 ft. Under each rail is a beam of Portland cement concrete 8 x 15 ins. in section. The concrete under rails and paving is carried along as nearly as practicable at the same time in order that both pavement and track may rest on a solid floor. While this has been used but a short time on about 6 miles of track, it has given such satisfaction that it is believed this method of street railway construction is a partial solution of the problem of how to build permanent track in paved streets.

In the writer's opinion, two changes are necessary. The rail must be increased to a depth of 6 ins. and a grooved head used. The cost as described above is approximately, per mile of double track, according to figures furnished by the street railway company, as follows:

Cost of track laying	$5 200
Cost of joints	1 000
Cost of concrete beam	5 300
Cost of rails and tie-rods	8 500
Track alone	$20 000
Asphalt paving, strip 18 ft. wide—$2 53, 10-year guaranty	26 717
Track and paving	$46 717

Mr. Cappelen. F. W. CAPPELEN, M. Am. Soc. C. E.—On ordinary railroads the entire line is practically constantly patrolled, so that bed and track can be kept in as good a condition as the management desires. Low joints are readily raised, bad ties easily exchanged for good ones, bolts tightened, etc., as every thing is in plain view to the men in charge. The conditions are entirely different on a street railway. After the track is down nothing is visible but the top or running surface of the rail, and when a joint sags it means the ripping up of the pavement of the street at that point to bring the track to proper alignment and grade. The same is the case when removal of ties or rails becomes necessary. In addition to the cost of properly caring for the track itself comes the cost of repairing the pavement between the tracks, it

being taken for granted that the corporation owning the street railway will at least care and pay for the pavement in the space from the outside rail on a double-track road. The repair bills of a street railway system operated with horses were comparatively small, although the track construction was generally poor. The cable roads made far better track construction an absolute necessity, and companies that attempted and are attempting light and poor track construction for electric street railways have found or will find that the expense for maintenance of track is a big item. Mr. Cappelen

The city of Minneapolis was one of the first in the United States in which the horse railway system was changed into an electric system, the entire change of 100 miles being made in a year. The company did not, however, change track and rail very much, but used a great amount of 4-in. light rail, 45 and 54 lbs. per yard. The Johnson 78-lb. girder rail was also used, and after considerable wrangling, the city council permitted the company to use the Shanghai 6-in. 70-lb. T-rail on some new extensions.

As most of the streets were paved with 6-in. cedar block on 2-in. foundation plank, much trouble was experienced with the pavement next to the rails and between them. The ties had to be cut down or 4-in. blocks used. With the 6-in. T-rail, strips of wood were placed along the rail to form the groove for the flanges of the car wheels to run in. The rails were spiked to pine ties on 2 ft. centers and almost anything used for ballast. In many cases cobble stones were used between rails. The city charter, however, provides that the space between rails must be paved with the same material as the balance of the street, but the city council would occasionally grant the company the right to do differently. After a while asphalt was ordered on certain streets, and the street railway company was obliged to look at the matter of track construction in a little different way; it finally received permission to pave between rails and tracks with granite, and the city put granite toothing on the outside of the rail. The 6-in. 78-lb. Johnson girder rail was used, but no particular care was taken in the ballasting of the tracks, and the result was, of course, that it settled and the asphalt broke away after a short period.

This year several principal down-town streets were ordered paved, and the writer was delighted to learn that the street railway company would do everything in its power to construct a first-class track in every respect. For all crossings and curve work, the so-called Johnson guaranty work was used. All switches and frogs have removable Harveyized steel pieces, and it is expected that this work will stand in the worst places at least nine years. The life of the old frogs, etc., did not exceed five years, and they were generally pretty bad after two years' wear. Ties were used for this part of the track; they were set in concrete and the entire intersection and cross-overs were paved with

Mr. Cappelen. fine-cut granite set in cement mortar with the joints filled with cement. For all straight track work, 60-ft. T-rails were used. The rail is the 80-lb. section recommended by a committee of the Society. Three methods of constructing the track were followed, each being an improvement upon the former, at least according to the ideas of the writer and the company.

The same company owns the street railway system in Minneapolis and St. Paul, and the work was commenced in St. Paul somewhat earlier than in Minneapolis. The first plan adopted there was as follows:

After the sub-foundation had been thoroughly rammed or rolled, the necessary slight excavation was made for a concrete beam to run longitudinally under the rail. This beam was $8\frac{1}{2}$ ins. in depth, 15 ins. wide, and constructed so that the top surface would be at the proper grade to receive the base of the rail. The beam was formed between boards. The concrete used consisted of one part Portland cement, two and one-half parts of sand, and four and one-half parts of crushed rock. Upon the beams, after they had set, the rails were placed and tied together every 10 ft. with 2 x $\frac{3}{8}$-in. tie-rods set on edge, as shown in Fig. 46.

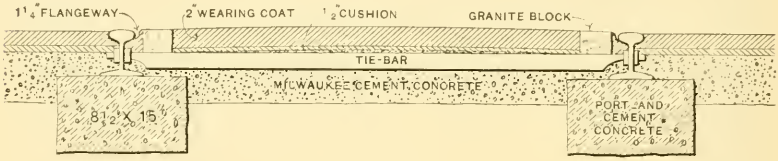

FIG. 46.

After the rails were lined up, the joints were welded, room being left in the concrete every 60 ft. for the joints. The street railway company experimented last winter with the so-called Falk cast-welded joints and adopted them for all the future work. The joint is made in the following manner:

The rails where the joint is to be made are first thoroughly cleaned with files and emery paper. Cast-iron molds are then placed around the joint, and held in place with clamp screws both horizontally and vertically. It was found necessary to have a heavy vertical screw to prevent the joint from heaving on account of the expansion due to the heat. After the molds were placed, the molten metal was poured and the joints thus completed. After cooling, the molds were removed and any rough edges left trimmed off. The joint is made so that a flangeway is formed in the cast. The company owns two of the so-called cast-welding machines. The cost of each is about $2 500, and its capacity 8 500 lbs. per cast. The joint for the 80-lb. rails requires about 138 lbs. of metal, and the cost, per joint, is about $2. This includes the cost of fixing the rails for the joint. A 45-lb. rail requires

102 lbs. for a joint, and a 54-rail requires 115 lbs. A mixture of half pig and half castings' scrap gives the best results. The furnace is loaded in layers, beginning with wood, coke and pig, coke, pig, etc. Mr. Cappelen.

After the joints were made, Milwaukee cement concrete, 6 ins. in thickness, composed of one part of cement to two and one-half parts of sand, and four and one-half to five parts of rock, was placed to proper grade to receive 2½ ins. of asphalt pavement across the entire street and between the rails and tracks, leaving enough space on the inside of the rails to lay granite blocks 4½ ins. deep, 3½ ins. wide, and 9 ins. long. These blocks were, however, set simultaneously with and in the concrete, being separated from the head of the rail by 1¼-in. wooden strip, so as to form the flangeway for the car wheels. After the strip was removed, the lower 2½ ins. of the space left was filled with cement grout, and the upper 2½ ins. to the top of the rail was filled with asphaltic cement consisting of about 30% asphalt and the balance limestone dust. This mixture remains soft enough to form the proper groove when the first car is run over the track. The joints between the granite blocks were filled with asphaltic cement. After the track work was completed, as described, the asphalt pavement proper was put down.

Considerable trouble was experienced in St. Paul with the rails after the joints had been cast. In a little while about 1 500 ft. of track looked like a snake, and it was very difficult to get it back in line; in fact the superintendent of the street railway company thought he would be obliged to cut the rails, which, however, did not prove necessary.

When the work came up in Minneapolis, this matter was discussed, and it was thought advisable to proceed in a different way. Ties were placed 6 to 8 ft. apart, and the rails were lined up and temporarily fastened to the ties; then the cast-iron joints were made, and the concrete beam put in between ties in the same manner as in the first case. The ties were then pulled out, the space filled, and the balance of the street concreted and completed as before. The rails were also spiked to the concrete beam as soon as it was in place. The track was kept in perfect alignment in this way. After discussing the work as it progressed, a further modification in constructing the beam was adopted. As it was not always possible to follow with the concrete work of the street proper as fast as the beam was built, a good bond was not obtained between the beam and the other concrete, so the method was changed. The ordinary concrete was put down outside and inside the rails, forming a rough groove about 8 ins. deep, 15 ins. wide at the bottom and 18 to 20 ins. at the top. In this groove, as soon as it was built, the beam concrete was placed, otherwise the construction was as in the second case.

The cost per foot of rail for the beam construction only, including grading, was 26 cents in the first and second cases, and 27 cents in the

Mr. Cappelen. third. The filler cost about 5 cents per foot. The cost of putting down temporary ties and laying, lining and surfacing 1 mile of single track preparatory to putting in the concrete beam, including labor and material used in welding the joints, was approximately $850.

In connection with this change of track construction, the writer changed the cross-sections of the streets as well as the intersections where repaving was done. All the old streets have very deep gutters, from 12 to 15 ins., and even more. This made it necessary at intersections to use aprons over the gutters at the corners, making them unsightly. The gutters were easily filled under the aprons, and too much space in the street was lost. Wherever repaving has been done, this was changed, so that now the gutters are only 6 to 8 ins. in depth, with the corners of the streets rounded off to a 12-ft. radius and the street raised at the corner, so that a step to the pavement of from 4 to 5 ins. only is needed.

Drainage is taken care of by putting in double catch basins. This makes beautiful intersections and pleases everybody. On a 50-ft. roadway paved with asphalt and without tracks, 8-in. gutters and 10-in. crowns are used; with tracks, 8-in. gutters and 7-in. crowns from the rail.

The cost per mile of double track constructed as related would be about as follows:

Cost of putting down temporary ties and laying, lining, surfacing, joints, etc., of a double track	$1 700
Beam work, etc	6 968
Rails and tie-bars *	9 400
Asphalt paving at $2 43 per square yard, ten-year guaranty	15 840
Total, per mile	$33 908

This is a very heavy expense, and it is sincerely hoped that the construction will prove satisfactory. About 2½ miles have been completed this season in Minneapolis. Brick was used on one street with the same track construction. In place of the granite blocks a special grooved brick fitting under the head of the rail was used.

So far as the writer knows, this construction has only been employed elsewhere in Montreal and Toronto, but without the cast-welded joint. The writer suggested to the company that a different rail be used, but as the season was too far advanced when the streets were finally ordered repaved, the company claimed that a different rail could not be obtained. The writer would suggest that the rail shown in Fig. 3 be used, but with a 6-in. base instead of one of 5 ins. This would give a better bearing on the concrete beam, and permit the use of deeper granite blocks, which, also, would be placed in staggered position.

* 60-ft. rails cost $2 a ton more than 30-ft. rails.

There hardly seems to be any necessity for a 9-in. rail, particularly if a track construction like that just described is used. Some trouble is anticipated with the flange groove as built in Minneapolis, but as several main streets with an electric railway have a width of 64 ft. between curb lines, a very small percentage of the travel utilizes the car tracks, and in no case is the roadway less than 50 ft., which leaves a double-team track on each side of the car tracks. Mr. Cappelen,

Mr. Owen mentions as an ideal road with trolley tracks, Beacon Street, Brookline, Mass. Minneapolis boasts of a road where the arrangement is different, and certainly the whole makes a beautiful appearance. This road is Hennepin Avenue Boulevard, with a 66-ft. roadway between curb lines. The trolley tracks are in the center occupying 18.5 ft., separated from the rest of the street by curbs 6 ins. high. At street intersections the curbing disappears. The space between center curbs is sodded. The cross-section is shown in Fig. 47.

This road is not a business street, but one of the parkways used largely by pleasure carriages and bicycles. The trolley cars run very fast and at short intervals during the summer months.

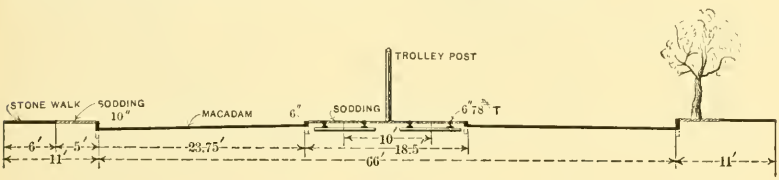

FIG. 47.

The city council of Minneapolis, according to ordinance, can demand that the street railway company clean the space of the street occupied by the tracks, practically 15 ft. The council also has the right to designate the style of rail to be used. These two laws are practically dead letters. The company has, however, in connection with repaving, been obliged to pave between the rails and tracks as the rest of the street is paved. The law should be changed so as to include a space 2 ft. outside of each outside rail. There are no penalty clauses in the ordinances, so the only way to enforce the latter, if it came to a fight, would be to declare the company's franchise forfeited, which can be done legally. The writer also thinks that the entire track construction should be according to standard to be approved by the proper municipal authority.

WALTER KATTÉ, M. Am. Soc. C. E.—The writer does not care to offer any opinion with regard to the various types of rails for ordinary street railroads further than to remark that he certainly thinks the section shown in Fig. 3 decidedly the best of all those shown and eminently suited for use for standard steam roads. Fig. 48 shows a preliminary sketch of the general features of an adaptation of this sec- Mr. Katté.

Mr. Katté. tion of rail to such purposes as would be required on standard gauge steam railroads for the heaviest class of locomotive traction. The broken lines give the outline of the Crimmins rail.

There are two points which Mr. North has overlooked in his discussion of the subject. The two greatest difficulties encountered in devising details of track for this purpose are :

First.—The ever-prevalent liability of worn flanges on locomotive driving wheels, technically known as hollow tire or false flange.

Second.—The minimum of gauge established by the Master Car Builders' Association between the inside of wheel flanges, which has been fixed at 4 ft. 5 ins.

The first of these causes, that is, hollow tire, is the reason of the $1\frac{9}{32}$ in. depth of flange groove referred to as being "unnecessarily great," in which the author is in error, for with hollow tire, it is not unnecessarily great, in fact, it is hardly deep enough. The answer to

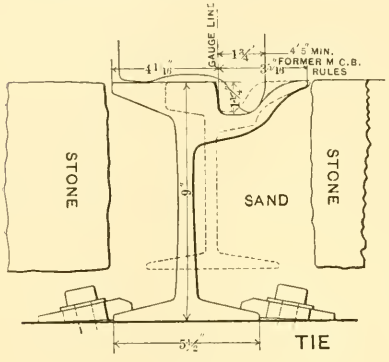

Fig. 48.

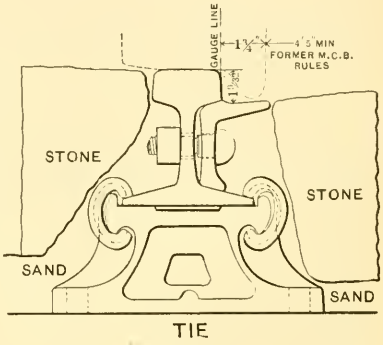

Fig. 49.

this will be, that hollow tire wheels ought not to be run at all, which, of course, in the abstract is quite true, but in reality they always are, and always will be run to a certain extent, and, knowing that to be the case, the writer has concluded to regard it as an established difficulty which must be met.

The soundness of the remark in regard to the objections to clipping off a corner of the paving blocks is recognized. In making a design, therefore, for a rail to meet these difficulties, the writer threw out a lip on one side far enough to carry false flanges, and on the other side has made the groove just wide enough to take in the minimum, back to back, wheel gauge, and with an extreme width to admit of easy placing of paving blocks without the chipping objected to. The girder rail shown in Fig. 48 figures up about 160 lbs. to the yard, but with some refinement in its lines it can be brought down to 150 lbs. without in any way compromising necessary strength.

The writer can hardly endorse Mr. North's opinion concerning the crossing made by the New Jersey Central Company. He does not regard it as very good for three reasons; first, it is clumsy looking and difficult to make; second, it is very uneconomical in its use of material, and hence, very expensive; and third, it takes no account of hollow tires. Mr. Katté.

It has been roughly estimated that the probable cost of such a track as is shown in Fig. 48 will be about $2 per lineal foot of single track, probably a little less. This, of course, does not include the concrete sub-foundation. The system shown in Fig. 49, of which the writer laid about 2 miles of double track through Washington Street, in the city of Syracuse, with the New York Central standard 80-lb. rail, cost about $2 55 per lineal foot. He is therefore now quite satisfied that the 9-in. girder rail can be devised and laid at less cost and make an infinitely more perfect track.

A. A. Schenck, M. Am. Soc. C. E.—Mr. Katté has given a general statement of his views as regards steam railways in cities and rail sections for them. The compound rail of the New York Central and Hudson River Railroad, to which Mr. North has alluded, was designed for and put in use on Washington Street, Syracuse, in 1893. On this street the railroad company expended $160 000 along an extent of about 7 000 ft. of the street. The rail used is shown in Fig. 49. Objections as to depth and width of flangeway in this design are raised by Mr. North. As regards width of flangeway, this was made practically of indefinite width, by keeping the paving block on the inside of the rail down to the level of the tram rail. There was no slot or flangeway. This, of course, gives a wagon crossing the track much more of a jolt than if the block be kept up to level of top of rail, but for a wagon traveling on the track and attempting to leave it, there is room for the wheel to turn. It has not the objectionable features of the high block, which in connection with the rail head forms a deep, square groove, very difficult for the wheel to leave. Probably Mr. North had this high position of block in view when he referred to a clearance width for the flange. The low position of the block, although it causes a jolt in a wagon crossing at right angles, is the same as is used in asphalt work, where it is not readily practicable to keep the asphalt above the rail. The low block is also undoubtedly undesirable in some respects, not only because of the jolt to the wagon crossing at right angles, but because it leaves at a low level the wagon wheel seeking to turn out, giving it a difficult climb over the rail while in a disadvantageous position for doing so. The Crimmins rail, Fig. 3, introduces the feature apparently best adapted to relieve this trouble, as stated, by the reaction against the rail head, combined with the smooth surface of the metal of the curved flange. Such a smooth sliding surface is impracticable in stone, and it would seem desirable Mr. Schenck

Mr. Schenck. always to have such a curved surface or flange in any street rail section.

In the Syracuse rail, the width of tram rail is only what the old Master Car Builders' minimum of 1886, back to back of wheels, of 4 ft. 5 ins., calls for, keeping the tram rail out to the back of wheel (see Fig. 49). Most of the car wheels of the country were placed when this minimum was in force. The depth of flangeway was put at $1\frac{9}{32}$ ins.; the standard wheel flange is $1\frac{4}{32}$ ins. It will, therefore, be noticed that only $\frac{5}{32}$ in. was allowed for wear of rail and tire. In practice this depth has been found not quite enough to prevent the rolling stock from bearing on the tram rail. The trouble so far has been due to hollow tires only, the rail not having worn appreciably since it was laid. It is sometimes supposed that no hollow tire whatever is allowable. The Master Car Builders' reports and code of rules for repairs to interchange cars call for replacing of wheels only when the tread is worn so hollow as to render breakage probable. On leading railways the practice is to send passenger engines to the shops when treads are hollow from $\frac{3}{16}$ to $\frac{1}{4}$ in., and yard engines when treads are hollow from $\frac{1}{4}$ to $\frac{3}{8}$ in. The writer has measured or taken plaster casts of several treads that were hollow $\frac{3}{8}$ in., and in one case $\frac{1}{2}$ in. was found. While such extreme cases may be against all rule, yet one such engine in a dozen years going over a track, with or against rules, will be sufficient to injure miles of tramway of improper section and flangeway. The false flange of the hollow tread is found also to injure the paving on the outside of rail, either by crushing the blocks or crowding them out of position. Such crowding is not merely by depressing them vertically. The pressure coming on one edge of the block, the tilting action is sometimes demoralizing in many ways. Although the outside blocks might be kept low by the amount of false flange, yet in practice, either in the paving process or from the effects of weather, the blocks will be found high, especially if the track settles at all. The method of carrying the false flange on the rail head by widening the head, relieves this trouble and also allows the flangeway to be made more shallow, as the flange does not settle down in it because of a hollow tire.

The combination of a rail head widened on the outside, with the Crimmins curved flange, and with a web deep enough to avoid chipping the paving blocks, is shown in the new design now being considered by the New York Central and Hudson River Railroad Company. Fig. 48 shows a section of such a combination. The estimated first cost is about 20% less than in the Syracuse plan, and the maintenance cost should be very much less, on account of the reduced number of pieces. The Crimmins rail, apart from the question of bearing for false flange, is not well adapted for heavy railway rolling stock, the head not being over the web, and it was not designed for such use.

Some of the points of enquiry that may be raised in connection with this rail are the strength of the widened head under the false flange; the tendency to tilt, the false flange not being over the web; and the tendency of the curved flange to bend under pressure from the wheel flange. The strengthening of the widened head under the false flange is very cheaply done for any required weight, involving thickening only 2 ins. of the outline. Mr. Schenck.

The tilting tendency is counteracted by the roadway material on each side of the rail, leaving much less duty for the fastenings at the base than with an ordinary 6-in. 100-lb. rail unsupported on either side.

The pressure on the curved flange is measured not by the weight on the wheel, but by the lateral sliding resistance of the opposite wheel. There will rarely be much pressure on the curved flange. With wheels set on the minimum 4 ft. 5 ins., and a worn flange on one wheel, the opposite wheel can get well out on the curved flange, but in this case the curved flange would simply have to act as a guard rail rather than a bearing rail. The low rates of speed in city traffic will greatly lessen the duty of this flange as a guard rail. It can be readily and cheaply increased in section if experience so dictates.

J. M. Evans, Jun. Am. Soc. C. E.—The Department of Public Works in the city of New York during the summer of 1896 adopted and used the following construction for the repaving of First Avenue. The street contains two railroad tracks covering a space of about 16 ft. in the center of the street. On the outside of each outer rail 8 ft. of granite was laid on a 2-in. sand cushion resting on 6 ins. of concrete, when the longitudinal grade of the street was $2\frac{1}{2}\%$ or more. Between the granite strip and the curb 14 ft. of asphalt was laid on the old stone paving blocks, which were in all cases repaved, for a foundation. It is the custom of the Department to set 8-in. and 12-in. toothing stones alternately along each rail. These toothing stones are set directly on concrete mortar and rammed to the level of the tread of the rail before the concrete sets, then the joints are filled with tar and gravel. The tar and gravel joint, however, does not extend entirely around the outer ends of the stone, these ends being banked with moist earth to prevent the tar from running out. This construction was followed in laying the granite next the track, but it was impossible to follow it at the outer edge of the granite strip, as the toothing stones at this point were laid upon the customary 2-in. sand cushion. The traffic over these stones necessary for construction caused them to settle or tip down on the sand foundation, thus leaving a depression at the joint of the asphalt and granite. The toothing stones at this joint were poured with tar, the same as the stones next the rail, that is, about half of the stone received the tar and gravel joint, the other half being left open to receive the asphalt. To pre- Mr. Evans.

Mr. Evans. vent the settling of the toothing on the latter part of the work, the speaker caused the foundation pavement for the asphalt to be first rammed, thus bringing it to a bearing against the toothing, then rammed the toothing into it, and finally made a tar and gravel joint around the entire stone. This securely bound the toothing to the foundation of the asphalt. The result of this method of setting the stones gave entire satisfaction and even surpassed his expectations. He has several times seen a 9-ton roller run over the stones thus set before the asphalt was laid, without depressing them sufficiently to break the bond between them and the next course.

Mr. North. EDWARD P. NORTH, M. Am. Soc. C. E.—An apology is due for the careless description of the steel plate laid on Chambers Street. The edge nearest the rail was laid substantially flush with the toothing stones, which are there laid against the stringers, supporting a center-bearing rail. The surface of the outer edge was depressed about $\frac{3}{4}$ in. below the surface of the asphalt. The holes mentioned were made by a punch which left projections on each side of the plate. These projections took the wear of the wheels next to the toothing, but retained the asphalt between them. At the outer edge of the plate they were covered. A more careful description of the piece of plate would probably have saved some reasoning about its probable inadequacy to prevent the formation of any rut.

Mr. Pratt seems to have adopted an exceptional case for his standard section, showing the pavement on First Avenue. The intention was to have the granite blocks laid just flush and in the same plane with the tread of the rails, and this has been generally accomplished. Fig. 20 is unfortunate, as many readers who are hurried for time pay more attention to cuts than to the text. This figure is also misleading, as no asphalt has been laid either between the rails or between the tracks. That area was paved by and at the cost of the Metropolitan Street Railway Company, and the pavement laid by them illustrates the statement of Mr. Lewis : "The railways will do no more than they are required, and nothing if they can avoid it."

Mr. Waring's statement, which is probably founded on a careful comparison of the cost of areas swept, shows that on sweeping alone there would be a yearly saving of $500 000 if the streets on which the grades did not forbid were paved with asphalt. This sum, at an interest rate of $3\frac{1}{2}\%$, represents a capital of over $14 000 000, a sum more than sufficient to put asphalt on all the streets of Manhattan Island where the grade would not be too steep.

As it has been said that the statement : "The laws of the State of New York make it obligatory on all surface roads to pave and keep in repair the space between the rails and tracks and 2 ft. outside of the same," is plainly erroneous ; that part of Section 98 referred to, which deals with repaving streets, is quoted, namely :

CHAPTER 565, SECTION 98, LAWS 1890, AS AMENDED BY CHAPTER 676, LAWS 1892. Mr. North.

"*Repair of Streets; Rate of Speed; Removal of Ice and Snow.*—Every street railroad corporation, so long as it shall continue to use any of its tracks in any street, avenue or public place in any city or village, shall have and keep in permanent repair that portion of such street, avenue or public place, between its tracks, the rails of its tracks, and two feet in width outside of its tracks, under the supervision of the proper local authorities, and whenever required by them to do so, and in such manner as they may prescribe. In case of the neglect of any corporation to make pavements or repairs after the expiration of thirty days' notice to do so, the local authorities may make the same at the expense of such corporation." * * *

This quotation, it is thought, will render unnecessary any future reference to the laws of the State of New York as understood by the surface railway companies in the city of New York.

The advantages of the Stanley rail (Fig. 28), which is substantially of the same section as that used in the District of Columbia, as "the best section of simple girder rail, from the pavement standpoint, yet adopted for streets," are fully recognized; the flange or tram of the rail being of the same height as the tread, and probably presenting mass enough to resist wear about equally with the tread. The vertical sides also are very desirable, but a surface railway company undoubtedly has some rights. Among these is a flange rail that does not entail too much expense from dirt in the slot, nor unnecessarily bind the flanges of the wheel. In other words, the rail shown in Fig. 3 is endorsed as not being onerous to railway companies and at the same time preserving the rights of the public in the highways its money has provided. The sharp edge in Fig. 3 is not, in practice, as objectionable, from the pavement standpoint, as it appears in theory, as the hard terra-cotta fillers used by Mr. W. Boardman Reed, the engineer of the Metropolitan Street Railway Company of New York City, give a very solid bearing for pavement of any kind, and the combination seems to the author much better to pave against than the simple Stanley section, though possibly not better than that section combined with Mr. Reed's filler blocks.

Mr. Victor Angerer apparently contends that there is advantage in keeping the wagon traffic of a city or town on the tracks of surface railways. Such a concentration of traffic, however, must retard the speed of cars and bring an expensive wear on the rails, while broad-gauge wagons develop unsightly, and, in time, costly, grooves in the pavement. The interest of the capital invested in surface railways seems to lie in having the pavement alongside their tracks so hard and even that traction will not be lessened on their tracks, and, at the same time, the rails should present the least possible side friction to the wheels of

Mr. North. wagons that are on them. The provisions for leaving streets dirty seem more inimical to the interests of cities and towns than the proposed concentration of traffic on the rails.

The section of rail proposed by Mr. Katté for freight and passenger roads will interest and please both the engineers having charge of paved streets and those connected with railroads, as its general adoption will remove the weighty objection to the extension of freight tracks in urban localities devoted to such trades and commerce as require the transportation of heavy merchandise.

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THE SUBSTITUTION OF ELECTRICITY FOR STEAM AS A MOTIVE POWER FOR SUBURBAN TRAFFIC.

No. 803.

By JOHN FINDLEY WALLACE, M. Am. Soc. C. E.

PRESENTED FEBRUARY 3D, 1897.

WITH DISCUSSION.

It is not the intention of the author in this paper to treat exhaustively of the question of the substitution of electricity for steam in the handling of heavy suburban traffic, but rather to give a concise statement of the history and results of certain investigations made by him, to the end that the *Transactions* of the American Society of Civil Engineers may contain a record of the progress which has been made in the use of electric motors for transportation purposes, and to lay the foundation for future papers on this subject. The author does not pretend to any expert electrical knowledge, and requests an open criticism of any remarks made herein by experts in this branch of engineering.

In December, 1891, the author was called upon by the management of the Illinois Central Railroad to examine into and report upon the

practicability of transporting large numbers of passengers between Van Buren Street, in the city of Chicago, and the grounds of the World's Columbian Exposition. As it would not be economical to establish a special service for the short exposition period which could not be utilized thereafter, the question of substituting electricity for steam as a motive power to handle the regular suburban business of the Illinois Central Railroad was a necessary sequel to the original proposition. An examination was made of the principal electric street lines in various cities of the United States. At that date none of the railroad lines that were originally steam roads had adopted electricity as a substitute for steam. So far the application of electricity for transportation purposes in the United States had mainly been confined to its substitution for horse-power on street railway lines and in the establishment of new lines of this character, in which the units of transportation were necessarily small and were moved at frequent intervals through short distances. The problem naturally divided itself into three divisions:

First. Practicability.—(*a*) As to the possibility of carrying 10 000, 20 000 or 30 000 passengers per hour between the World's Fair site and Van Buren Street, in Chicago, by electricity. (*b*) The practicability, after the close of the World's Fair in 1893, of satisfactorily handling the suburban business of the Illinois Central Railroad by electric power.

Second. Economy.—(*a*) The cost of handling the World's Fair business between the Lake Front Park and the site of the Exposition by electricity, as compared with steam. (*b*) The cost of operating the suburban traffic of the Illinois Central Railroad by electricity instead of steam after 1893.

Third. Appliances.—(*a*) Line construction. (*b*) Power plant. (*c*) Motors and cars.

Granting that the application was practicable, the next question to be considered was economy. Should it be shown that it would be economical, the third question to be considered was the nature of the appliances to be used.

In order to secure the necessary data for an intelligent consideration of these problems, the prominent electric manufacturing companies in the country were asked to submit in writing their answers to a list of questions. As it is, of course, not advisable to disclose the

names of the companies giving the information contained herein, they will be designated as (*a*), (*b*), (*c*), (*d*) and (*e*). Following is a statement of the requirements and the questions submitted to each company, with their answers in regular rotation:

"In considering the question of passenger transportation facilities between the Lake Front Park, in the city of Chicago, and the Columbian Exposition in Jackson Park, it is desirable to know whether electric power can be applied for passenger service with economy. The following are the physical conditions:

"The track will be first-class standard gauge railroad track, and the maximum grade will not exceed one-half of 1 per cent. The distance between the terminal stations will be 7½ miles. Between these stations there will be practically no curvature. If possible, loops will be constructed at each end of the line, with a radius of about 300 ft. As a basis for the consideration of the question, it is estimated that trains should consist of one motor car and two trailers, with provisions for carrying 336 passengers. The dimensions of the motors and trailers would be from 36 to 40 ft. in length, with cross-seats, and the cars should be about 8 ft. wide in the clear on the inside. It has been estimated that these cars will weigh about 20 tons, loaded. It is desired that the speed should be about 20 miles per hour. It is estimated that the equipment required will be from 60 to 70 motors and from 120 to 140 trailers. Estimating that 112 passengers can be carried in each one of the cars, including the motor, each train would carry, as stated above, 336 passengers. Assuming that one train can be loaded and despatched from the terminal station each minute, the capacity per hour will be 20 160 passengers.

"Considering the above conditions and assumptions, in order to determine the advisability of adopting electric power, answers to the following questions are desired:"

Question 1.—What capacity should motors have in horse-power?

Answers.—(*a*) Capacity of motors, 75 H.-P. each, two on each axle.

(*b*) A 20-ft. motor car and two 40-ft. trail cars, as specified, could be operated at less than 75 H.-P. on an average, but the maximum required at starting, on grade and curve work, and with specially heavy loads, might raise these figures 50 to 75 per cent. It is, therefore, desirable to have, at least, two 75-H.-P. motors, one on each axle of the motor truck, and it is quite possible with the space at disposal to make these 100-H.-P. motors, that would be able to draw three or possibly four trail cars heavily loaded.

(*c*) The motor cars should have a capacity of 100 H.-P. each, but should be capable of developing up to 200 H.-P. for short periods of time without harm or injury to any part. The best way to attain this result will be to employ two Eickemeyer-Field electric motors

of 50 H.-P. each, one motor on each four-wheel swivel truck of the motor car.

(*d*) To handle a train of four cars, each weighing, when loaded, 25 tons, will require a draw-bar pull of nearly 1 000 lbs. This will mean a continuous development of about 50 H.-P. on the axle, and occasionally much greater power for acceleration, etc. We should, therefore, recommend four of our standard 25-H.-P. motors wound for 25 miles an hour. These will weigh each 2 500 lbs., approximately, so that four of them will add a weight of 5 tons to the train.

(*e*) Taking various measurements made on electric tramcars as a standard of comparison, 200 H.-P. will be required to satisfactorily operate a 75-ton train, making an average speed of 20 miles per hour.

Question 2.—What will these motors cost? In giving cost, separate the cost of motors and motor cars.

Answers.—(*a*) Cost of two motors, $5 000, with all regulating devices. Approximate cost of trucks, $3 000, making cost of electric locomotive $8 000.

(*b*) The motor car, body and trucks, without electrical equipment, will cost in the neighborhood of $1 500 to $1 750, depending on weight and finish. The motors would cost roughly $40 per horse-power, to which should be added about $400 per motor car for controlling mechanism, electrical appliances, wiring, labor, etc. Thus, a 150-H.-P. motor car would cost complete about $8 000, although these figures would be somewhat reduced in an actual bid.

(*c*) The Eickemeyer-Field motors will cost about $6 000 for each motor car. This figure includes trucks and ordinary brakes, but does not include air-brake apparatus. The cost of the car bodies will be approximately $4 500 each additional, making the cost of the motor cars, without air-brake apparatus, $10 500 each.

(*d*) The four motors, together with their controlling apparatus, contact trolleys and all other devices necessary to completely equip the car, will cost $5 000 per motor car. The cars themselves we should estimate at $2 000 apiece.

(*e*) No answer.

Question 3.—Give approximate cost of trailers. Cars to be open cars, with cross seats, on first-class double trucks.

Answers.—(*a*) Trailers to be furnished by the Illinois Central Railroad. Cost, about $3 000 each.

(*b*) We cannot at this moment make more than an approximate bid upon the cost of trail cars, as so much depends upon weight, style and finish. The cost would not exceed, however, $2 000, and would probably be a little less.

(*c*) The approximate cost of open trailers with cross-seats on first-class four-wheel double trucks is $3 500 each, with ordinary brakes.

(*d*) The trailers we should estimate at $2 000 apiece, which ought to furnish a car serviceable, not only for the World's Fair, but for suburban service afterwards.

(*e*) No answer.

Question 4.—Is it desirable to have horse-power used for motor cars consolidated in one unit or divided into two ?

Answers.—(*a*) It is desirable to equip each electric locomotive with two motors.

(*b*) There should be two motors for each motor car. In case one is disabled, the other would be in condition to pull the train in and clear the road without difficulty.

(*c*) It is desirable to have the power divided equally between the two trucks, and applied equally on all the wheels of both trucks, since by this means traction on all wheels will be secured, and in the event of one motor giving out, the other will run the train to the terminal. The motor car can be arranged to drive from either end, the driver's box being placed on one side of the center line of the car, so as to leave the usual free passage from car to car.

(*d*) It will be most desirable to have the motor power divided into two or four parts. The four-part division will give the most efficient means of control, speed and power. This will enable the use of the series-multiple controlling switch, whereby the motors can all be started in series for slow speed and then changed over to multiple series for intermediate speed, and finally thrown into multiple for high speed. A still further adjustment could be made by commuting the fields so that four different speeds, varying from 5 miles to 25 miles an hour, could be obtained with maximum efficiency, and without the efficiency dropping materially at intermediate speeds.

(*e*) With motor cars it is desirable that the horse-power should be divided into two units, the reason being that, in the case of the failure of one motor, the train is not completely disabled. Further, motors of 100 H.-P. would be more satisfactory electrically for varying loads, where the motors are not accessible to the operator. In the present case it is thought advisable to run these two motors in series, so that the electro-motive force on the line can be increased to 1 000 volts. With this electro-motive force, but one-fourth of the weight of copper will be required to transmit the same power as with 500 volts.

Question 5.—What is the best method to transmit the power of the motor to the axle, by gear or by crank ?

Answers.—(*a*) The best method of transmitting the power of the motor to the axle is by placing the armature directly upon the axle, or transmitting it by steel gears.

(*b*) No form of gear or crank transmission should be considered for a moment in work of this character. The armatures should be radial on the axle, and the motors of the utmost simplicity in con-

struction. It is estimated that 75% of the expense of maintaining geared motors is due to the gear in one form or another, not only by direct breakage of gearing, involving the necessity of replacement, but also by armature and field burnouts, due to "locked gearing" or other electrical difficulties, caused by broken parts getting into the revolving parts of the motors. Moreover, there is a constant and heavy drain upon the power station, caused by friction of gearing, which amounts even in comparatively low-speed work to at least 20% of the total power consumption. It is safe to say that motor gearing up to the present time has cost railway companies at least 1¼ cents per car mile on an average. Gearless motors for ordinary street car work have been designed and are now in regular operation at speeds slower than most of the new types of single-reduction motors, and with very high economy in power consumption and cost of maintenance. It is, of course, a much simpler problem to design gearless motors of larger power to run at higher speed and with a greater space at command obtained by the use of a 42-in. wheel instead of 30 and 33 ins. with which the street car gearless motor can be used. The gearless motor has many characteristics which give it great value in all classes of railway work. It starts from rest smoothly, attains speed quickly, and, having no gears to impede, it will bowl along over a smooth track at a cost for power much less than any geared motor. To fulfil your requirements, all that it would be necessary to do would be to increase the dimensions of the street-car motor, making a 33-in. armature instead of a 23-in., as at present, with fields and framework made to correspond. When it is stated that the power of an electric motor varies roughly as the cube of its armature diameter, all other things being increased proportionately, you will see what a simple problem it is to obtain the requisite horse-power in the way above suggested. In mounting these motors on the truck the armature will be keyed to a hollow shaft which will surround the car axle, leaving an annular space of at least 1½ ins. This hollow shaft will be carried in the frame work of the motor itself, hung on strong cross-girders of the truck through flexible rubber bushings of special design. The entire truck frame and motors will thus have an easy spring movement, which will prevent pounding on the track, breakage of wires, etc., which is always found in geared motors which are more or less rigidly attached to the framework. The armature is of the ring type, which permits of separate and independent coils, which may be rewound, in case of burnout, at nominal expense. This peculiar type of armature construction has been found by far the most satisfactory in street car practice, it being adopted by nearly every company. This company was the first to recommend its use, and the road operating it in Rochester, N. Y., is now making 250 000 car-miles per month, at a cost for repairs of less than ½ cent per car mile, although the motors are

of the double-reduction (four-gear) type. Further information upon the peculiarities of the gearless motor will be given verbally or upon request.

(*c*) The best method of transmitting the power of the motor to the axle is by cranks and parallel rods; this calls for a motor which turns its armature at the same speed of rotation as car axle. At first sight, this comparatively slow armature speed might appear objectionable, but it has been found easily possible in practice to so design and construct a motor that under these conditions it will surpass in commercial efficiency any form of motor as yet applied to work of this character. As bearing out our statement that cranks and parallel rods are the best means of connecting the motor to the axle, we have only to point to the engineering practice with steam locomotives for the past 40 years. Again, in mine hoisting machinery, gearing has been almost entirely abandoned, the engines being connected directly to the cable drum.

(*d*) In case only 25 miles an hour is desired, the best method would be by the use of spur gearing—gearing the armature directly to the axle. This will enable the use of standard motors of light weight and render repairs easy. The gears, being single reduction and run in oil, will be practically noiseless, and the wear and tear will be very slight.

(*e*) The best method of transmitting the power to the axle which we are familiar with is the spur gear. Cranks have been used from time to time for this purpose, but the information we have gathered on this subject has not been favorable to the use of these cranks.

Question 6.—What parts of motors are liable to give the most trouble from breakages, and what is the best and quickest method of handling motors that are disabled out on the line, and to avoid the least delays to traffic?

Answers.—(*a*) By using best standard motors there will be no trouble from breakage. In case one motor should be disabled electrically, the train may be run into the terminal station with the other motor and then be repaired.

(*b*) The most trouble from breakage is experienced with gears, which is obviated in the motor described in Answer 5. There is also some liability to burn out armature and field coils in electric motors, if heavily overloaded; but with the type of motor referred to, these burnouts are of very rare occurrence, because of the independence of the armature coils and the fact that they are thoroughly ventilated. Moreover, the burnout of more than one coil at a time is a very rare occurrence, and the motor will do work and help to carry the train through to the terminus, even if several coils are burned out, a very important feature. However, in general plan outlined as above, there is ample power in one motor to draw a train in, so that complete stalling of the train on the road would be very rarely experienced.

(*c*) The parts of motors most liable to give trouble by breakage are the armature and the commutator. This is not saying that these parts are very liable to give trouble, but simply that they are the most liable. The best and quickest way of handling motors that become disabled out on the line is, in case both motors are disabled, to push the train in by the next motor coming along, which, owing to its allowance for development of extra power, should do the work without injury to it. In case but one motor of the car should be disabled, the remaining motor would run the train to the terminus, where it could be exchanged for one of the reserve motors. In the event of such damage to a motor that its shaft would not revolve, the connecting rods could be quickly removed, and the wheels and axles would then serve as an ordinary truck.

(*d*) The parts of the motor most liable to require repairs are the bearings and gears, but these have been so perfected in the last year that their maintenance is about as small as any piece of mechanism could be expected to be. Duplicate trolley wires, duplicate trolleys, duplicate motors and proper cut-out switches will enable a motor car disabled in any of its parts to complete its round trip in any conceivable case. Should, however, such a breakdown occur as cannot be foreseen, and the motor car be completely disabled, it would have to be pushed to the terminal station or to the nearest siding by the train in the rear, and the motors would have abundant power to handle two trains if necessary.

(*e*) With proper system of inspection, there is very small liability of the breaking of any part. The gears require replacing oftener than other parts, but a mechanic should be able to tell from the condition of the gears how much longer they are to be relied upon. The brushes on the commutator would require attention about as frequently as the journals. With proper care these very rarely cause trouble. In case a motor car becomes completely disabled, the best method of avoiding delay would be to side-track the train. One or two motor cars could be held in readiness along the line, so that no serious delay would be possible.

Question 7.—What is the best-known brake for electric cars and motors suitable to the requirements of this line?

Answers—(*a*) The best-known brake for electric railway trains is the Westinghouse air brake. The air pump can be operated by a small separate motor on the locomotive, and all the air-brake appliances will be practically the same as those now in use on steam roads.

(*b*) You should use a Westinghouse air brake of the usual description. We would place in the motor car a small electric motor, geared to an air pump, which would furnish the required power for working the brakes. You would thus have the best working power found in any system of street railway locomotion.

(*c*) The best brake for motor cars and trailers operated in a train, as required, is the air brake.

(*d*) A compression air brake would be the most reliable to use in connection with a system of this kind, the air pump to be operated by a separate electric motor on the motor car and controlled by the driver.

(*e*) The best brake for practice of this sort is the air brake.

Question 8.—What is the largest motor now manufactured, and where is it operated ?

Answers—(*a*) The largest motors which this company has constructed for suburban railway service are of 30-H.-P. capacity and are in operation in Sioux City, Ia.

(*b*) We have built 100-H.-P. motors for transmission of power purposes, and dynamos up to 500 H.-P., any of which could be used as motors of the same power on occasion. For railway work, the largest motors yet manufactured in this country are 30-H.-P. motors, which are being put out by the various electrical manufacturing companies, ourselves among the number. In England, the London and South Western Company is using large motors of the gearless type for the operation of their cars under ground, these cars being, as we understand, of the long double-truck type, similar to those which you will require.

(*c*) The largest motors of the type recommended, now in use, are of 30 H.-P., and are capable of developing 50 H.-P. for short periods of time with higher efficiency, and without injury to any part of the motor. Those 30-H.-P. motors are in operation at Toledo, O. They are each mounted on a four-wheel truck of 4-ft. 8½-in. gauge, having a wheel base of 6 ft. The wheels are 26 ins. in diameter, and make 265 revolutions when the car is going 20 miles an hour, which speed is frequently attained. These motors, with trucks complete, weigh 4½ tons, and upon each is mounted a 16-ft. street car body, weighing 3 tons, making the total weight of the motor car complete, 7½ tons. Fifty passengers can be carried in one of these cars without straining or overloading the motor. Curves of 32-ft. radius are rounded without difficulty, and, owing to the small diameter of the drivers, the tendency to leave the track on curves is very slight. In Boston, a 40-ft. car propelled by two 20-H.-P. motors, each mounted on a four-wheel swivel truck, is in use, the motors and method of connection being the same as herein recommended.

(*d*) The largest motor in existence is the freight locomotive at Whitinsville, Mass., rated at 120 H.-P., but which has given an actual draw-bar pull of 10 000 lbs.

(*e*) The largest stationary motor in operation is the 100-K.-W. motor, manufactured by the Edison General Electric Company. This motor is in operation in the Schenectady works and in various other.

plants. The largest motor outfit with which we are familiar is the 60-H.-P. equipment manufactured by the Edison General Electric Company. This is in operation upon the Schenectady Street Railway and various other railways.

Question 9.—In using two motors on a car it was understood that the motors work separately on both forward and rear trucks, and that the motor cars do not have to be turned at end of line.

Answers.—(*a*) Using two motors on each locomotive, the train can be operated the same as with steam-power.

(*b*) See answer to Question 10, which is for Questions 9 and 10.

(*c*) The two motors, thus applied to the car, will each work independently of the other end upon its own truck. The motor cars can be driven from either end and in either direction.

(*d*) The four motors would all work in unison, but any one or more could be cut out and the other motors do the work. Motors can be run either way and reversed with a single switch. Each can be controlled from either end of the motor car, and the car can be treated in every respect as a double-ended locomotive.

(*e*) The statement made that the motors do not have to be turned at end of line is correct.

Question 10.—Can both motors be used at once in the same direction, and can motors be reversed on line in an opposite direction, and can both motors be operated from same end of car?

Answers.—(*a*) Both motors can be used at once in the same direction, and may be reversed on the line in an opposite direction, and both motors may be operated independently of each other. With one motor in operation, the speed of the train will be considerably less than 25 miles per hour.

(*b*) Both motors can be controlled from either end of the car to work together in either direction; in other words, you can do with them precisely what you can with a locomotive, and, in addition, you can never speak of the motor car as running backwards, as it is symmetrical in form.

(*c*) Both motors can be used at once in the same direction and can be reversed on line from either end of car. Both motors can, of course, be operated from same end of car.

(*d*) Unless a motor is disabled, all the motors will be used simultaneously, as this gives the most efficient service and least heating of motors.

(*e*) Both motors can be used at once in the same direction. The motors can be reversed on the line in an opposite direction, and both motors can be operated from the same end of the car. The above conditions are common to street railway practice.

Question 11.—If the motor is designed for a speed of 20 miles an hour, with a certain load, can the speed be increased with a less load

without overstraining the motor and without any change in the mechanism, and what percentage can speed be increased ?

Answers.—(*a*) The motors will be so designed that when hauling a load of 150 tons they will run at a speed of, say, 25 miles per hour, and with a less load they will run faster without overstraining and without any change in mechanism. The speed will increase nearly in direct proportion as the load decreases.

(*b*) The answer to this question depends upon the characteristic curves of the motor. In a general way, it may be said that we can design and build a gearless motor car which would operate about as follows : In starting a 70-ton train, it would take, perhaps, 125 E. H.-P. During the period of acceleration up to a speed of 20 miles per hour, the power would gradually fall from 125 H.-P. to, perhaps, 50 to 60 H.-P., or even less, the power exerted being required in overcoming friction of journals, etc. With a 50-ton train, the speed would, perhaps, reach 22 to 25 miles per hour, or a slightly greater speed than that of the 70-ton train, but it is a peculiarity of our special method of building motors than the speed under heavy loads does not fall greatly over that required for light loads; in other words, the motors "stand up to their work" on grades or heavy tractive pull. It may be said in passing that it would not be feasible to run a geared motor as rapidly as a gearless, since the liability of breakage would be much greater.

(*c*) Motor cars can readily be constructed so that while adapted for a speed of 20 miles an hour, with a certain load, their speed may be increased to 25 or 30 miles an hour with less load. The speed may even be increased with the same load without overstraining the motor and without a change in the mechanism.

(*d*) The motors designed to run 20 to 25 miles an hour would not be able to go over 35 miles an hour on the level with a light load.

(*e*) If the motor is designed for a speed of 20 miles an hour with a certain load, the speed can be increased with a less load without straining the motors and without any change in the mechanism. It is safe to say the speed can be increased 50% and not exceed the ordinary conditions of good practice.

Question 12.—In how short a distance can trains described above be brought to a stop with existing brakes from a speed of 20 miles per hour?

Answers.—(*a*) The train may be brought to a standstill by the Westinghouse air brake in about 100 ft.

(*b*) With air brakes only, as described, the result would be the same with electric traction as with steam. There is, however, an additional safeguard in an electric locomotive not possessed to the same degree by a steam locomotive. The motors may be instantly reversed by turning the controlling handle in such a way as to actually turn the wheels backward while the train is going forward, thus accomplish-

ing an extremely quick stop. This, however, is to be applied only in the most extremely urgent necessity, as the results are apt to be disastrous from the enormous amount of power necessarily going through the motor. In ordinary service an 80-ton train can probably be stopped within 400 to 500 ft.

(*c*) With air brakes a train of three cars can be stopped, under ordinary conditions of rail service, from a speed of 20 miles an hour within a distance of 350 ft. without excessive jarring.

(*d*) The theoretical distance for stopping a train going at 20 miles an hour would be about 80 ft., but it would not be safe to count on less than 120 ft. under the most favorable conditions, since the driver cannot always gauge his braking power to his load. Taking in all kinds of conditions and distances, all of 200 ft. should be allowed for stopping from a speed of 20 miles an hour.

(*e*) If brakes are put on each car, and the described conditions indicate that they should be, the train moving 20 miles an hour can be stopped in a distance of 200 ft., with ordinary conditions of track.

Question 13.—Upon the line under consideration, what would be the best location for the power house, taking into consideration that after the World's Fair the line will be extended 7 miles south and that trains will have to stop at suburban stations at intervals of ½ mile?

Answers.—(*a*) The best location for the power station will be the center of the line.

(*b*) The best location for the power house is always as near as possible to the center of the road which it is to serve. Other considerations, however, frequently come in to disturb the best theoretical arrangement. It is important that coal should be delivered directly at the power house without cost of cartage, and, therefore, the station should be located near the railroad track. Moreover, in a plant of this size, it would be high economy to condense, and the question of obtaining a cheap water supply for this purpose should not be overlooked. It is impossible to state, therefore, without a comparative estimate of available sites, what would be the best location, but it may be said in general that in a 15-mile line you can safely work within a radius of 2 or 3 miles from the exact center.

(*c*) The best location for the power house, from considerations of economy in distribution of electrical energy and in cost of copper, would be at the middle of the length of the road; this is true whatever the amount of business or number of stops to be made. This is assuming that only one power house can be used. If the length of the road operated should be extended to 15 miles, with a very heavy traffic, it might become more economical to supply the electrical energy from two power houses than from one, but for a traffic extending over 7 or 8 miles, one power house, located at the middle of the road, would keep the cost within reasonable limits.

(*d*) The best location for the power house would be in the neighborhood of 3 miles from the city terminus, and as near to the middle of the line as possible. For subsequent extensions a suburban station would be built somewhere beyond Jackson Park. The stations would be so large that there would be no loss of economy in having two stations instead of one.

(*e*) It is not possible to give an exact answer to this question without knowing the exact value of real estate at various locations along the line; also, facilities for procuring coal. Neglecting these items, however, and taking into consideration the statements made to us that the traffic on this second 7 miles of track to be built after the World's Fair falls off with the distance from the terminus of the present contemplated road, we would say the station could be most advantageously situated within about 2 miles of the end from which the extension is to be made.

Question 14.—How much power plant would be required to operate from 60 to 70 trains of 65 to 70 tons each at a speed of 20 miles per hour?

Answers. (*a*) The power plant should have an aggregate generating capacity of, at least, 4 800 H.-P.

(*b*) You should plan for a power plant of 10 000 H.-P. to provide a sufficient margin for reserve and contingencies. Your average output should not exceed 6 000 H.-P., if you ran three car trains, but there will frequently be call for 7 500 H.-P. on special days when loads or conditions of track are severe.

(*c*) The power plant necessary to operate 60 to 70 trains at 20 miles an hour we estimate at 5 000 H.-P. capacity. This estimate is based on use of 1 000 watts electrical energy for each ton weight to be moved; practically, it would be found that with 60 trains running at 20 miles per hour the horse-power required at the house would fall below 4 000.

(*d*) To operate the above-described four-car train of 100 tons would require about 100 H.-P. in the engine, and, as 40 of these will be running at once, 4 000 H.-P. will be needed continuously during the hours of maximum travel; allowing a reserve of 20%, the total power required for the central station would be 5 000 H.-P.

(*e*) Basing our answer to this question on the present street railway practice, from 12 000 to 15 000 H.-P. will be required to operate from 60 to 70 trains of from 65 to 70 tons at a speed of 20 miles an hour. It is possible that in the present case less power would be required, owing to favorable conditions of track and the small number of stops to be made. We do not feel safe, however, in stating that a less power would be required until we have had an opportunity to make a thorough investigation of the whole matter.

Question 15.—What excess power will be required in such a plant, if any?

Answers.—(*a*) It is advisable that spare machinery of at least 8 000 H.-P. generating capacity be added.

(*b*) You will see from Answer 14 that we allow 25% reserve.

(*c*) No excess of power above 5 000 H.-P. would be required, provided the power units were not too large.

(*d*) Twenty per cent. reserve would be sufficient, provided the station is carefully installed and the apparatus of liberal capacity.

(*e*) In a plant of the present description it seems unnecessary that more than a 20% margin should be allowed. In street railway practice larger margins are generally allowed, but the demands for power in this case are liable to fluctuate very greatly, while in the present case the demand for power is nearly constant.

Question 16.—What would you recommend as to the proper units into which this power should be divided?

Answers.—(*a*) The smallest unit into which it would be advisable to divide this power would be 800 H.-P.

(*b*) We would recommend 1 000-H.-P. engine units and 500-H.-P. dynamo units, two dynamos being coupled direct to the shafts of each engine.

(*c*) We would recommend the division of power into twelve engines of 400 H.-P. each.

(*d*) The units could be either ten of 500 H.-P. each, or five of 1 000 H.-P. each. The former would give greater flexibility, and the latter greater simplicity. It would be a matter that should be decided largely by prices of engines and similar considerations that would come up during the further discussion of the problem.

(*e*) We would recommend as the proper unit of power for the above work 1 500-H.-P. engines and 750-H.-P. dynamos, two dynamos to each engine, the engines to be triple compound condensing, with Corliss valves.

Question 17.—If the requirements for power should be reduced 50% after the World's Fair, what power of each unit would you recommend?

Answers.—(*a*) Answer contained in Answer 16.

(*b*) The same as indicated in Answer 16.

(*c*) If the power plant should be reduced 50% after the World's Fair, we would still recommend the same units of 400 H.-P.

(*d*) In case the power plant was to be materially reduced, the smaller unit of 500 H.-P. would be preferable.

(*e*) We would recommend the same type of machine, if the power should be reduced 50% after the World's Fair.

Question 18.—How many square feet in space will be required for the erection of steam and electric power plant, including boiler house?

Answers.—(*a*) The number of square feet required for the erection of the steam and electric plant, including the boiler house, will be 75 000.

(*b*) You will require a lot of about 350 ft. by 125 ft., or the equivalent in area, in case you can purchase land cheaply; otherwise, it is possible to arrange a two-story building, with a little more than one-half this space.

(*c*) We estimate the space required in square feet for the erection of steam and electric power plant, including boiler houses, at from 15 000 to 25 000, according to types of boilers, engines and generators used, with everything on one floor; if two floors are used, the space required can be reduced to about 12 000 sq. ft., or even somewhat less, if necessary.

(*d*) The boilers will require 2½ sq. ft. per horse-power, or, say, a building 145 x 85 ft., and the engines and dynamos will require 2.61 sq. ft. per horse-power, or, say, a building 145 x 90 ft; so that a building 145 x 175 ft. would be sufficient for the whole power plant.

(*e*) About 27 000 sq. ft. will be required for the erection of steam and power plant, including boiler-house, and a room about 130 x 130 ft. for engines and dynamos, pumps, etc., and a room about 80 x 130 ft. for boilers. We would recommend two separate smokestacks, one on each side of the room.

Question 19.—Give your opinion as to the most economical and best kind of boilers, engines and generators to use for such a plant.

Answers. (*a*) In our opinion, the most economical and best boilers are the Babcock & Wilcox; engines, of the Corliss type, and generators, manufactured by the Westinghouse Electric Company.

(*b*) We would recommend large water-tube boilers with mechanical stokers; a high grade Corliss type of engine and slow-speed generators adapted for direct coupling to the engine shafts. It is unsafe to experiment with new or unusual types of boilers or engines, and nothing but what have been found in the past to be the most reliable under all conditions should be thought of.

(*c*) A water-tube boiler of Babcock & Wilcox or similar design we should consider most economical and best suited to your requirements. For engines, compound condensing, medium-speed engines, directly connected to generator, will give economical results, provided water for condensing can be obtained with little cost. The obtaining of water would depend on the location of the plant. The generators should be of 400 H.-P. each and operated at a voltage of 500 to 600. They can be either of bipolar or multipolar construction and should have a commercial efficiency of 80% or over when under full load.

(*d*) Babcock & Wilcox boilers should be preferred, and compound or triple-expansion engines of slow-speed type, with generators directly coupled to the same.

(*e*) We recommend the Climax type of boiler as the most efficient, economical and as requiring the least floor space. We recommend a vertical triple-compound condensing Corliss-gear engine, with

a sub-base plate or foundation box, on which would be erected the engines and generators, with two generators to each engine, one at either end of crank shaft, with armature coupled directly on the crank shaft. We recommend a multipolar type of generator.

Question 20.—Give approximate cost of power plant, to erect engines, boilers, generators, separately.

Answers. (*a*) The approximate cost of power plant, complete, ready to run, will be $475 000, not including real estate.

(*b*) The steam plant, complete, including engines, boilers, condensers, heaters and all accessory apparatus, together with piping, labor in erecting and everything necessary to make the plant ready for operation, will cost, in round numbers, $60 per horse-power. The electric plant, complete, including generators, switchboard, appliances, controlling apparatus and accessory apparatus, including labor in erecting and making ready for operation, would cost, in round figures, $40 per horse-power. The cost of the power station, complete, would therefore be, roughly, $1 000 000; this figure would easily cover also the cost of the building itself.

(*c*) We estimate the approximate cost of engines and boilers, erected, including necessary pumps and heaters, at $40 per horse-power. This would make a total cost of $200 000 for 3 000 H.-P. The cost of twelve generators erected would be $120 000.

(*d*) The power plant would cost $91 per horse-power, if constructed in a first-class manner. This figure will allow for slow-speed directly coupled dynamos and slow-speed compound engines of the most approved type, and boilers, furnaces, steam connections, pumps, condensers and economizers, all of the best and most reliable makes. It would also include the cost of building, for which an allowance of $10 per horse-power has been made. The dynamos have been estimated at $35 per horse-power and the steam plant at $46 per horse-power, and it is with the understanding that the plant is to be in every way ample and above actual rated capacity that the above figures are given.

(*e*) The approximate estimated cost of the twelve 1 500-H.-P. triple-compound engines, with two dynamos each, would be $1 000 000. The approximate estimated cost of the boilers would be $144 000, and the necessary piping, pumps, etc., to the amount of about $20 000 to $25 000.

Question 21.—Give estimated cost for operating power plant, with coal at $1 per ton.

Answers.—(*a*) We estimate that the cost of operating the power plant, with coal at $1 per ton, will be $60 000 per year, including all fuel, labor and repairs.

(*b*) It would be entirely safe to figure upon $30 per horse-power per year in a station of this size, operating for 18 hours a day. The cost of generating, therefore, 7 500 H.-P. would be $225 000 per year, which should cover all expenses.

(*c*) When running at full capacity, the cost of fuel per hour, with coal at $1 a ton, would be about $4. This gives 2 lbs. of coal per horse-power per hour. The expense for firemen, engineers, generator attendants, we estimate at about $4 per hour. This would allow ten firemen at $2 each per day; two engineers at $5 each per day; one head generator attendant at $5 per day, with two assistants at $2 50 each per day.

(*d*) In the following estimate the interest and depreciation are included so as to enable the railway company to make a ready comparison between the electrical system and the steam system. No account is taken of the maintenance of cars, trucks, roadbed, etc., as these are believed to be common to both systems, with a slight advantage in favor of electricity, because of its greater cleanliness and greater ease on the roadbed.

CENTRAL POWER STATION.

Capacity, 5 000 H.-P.; maximum duty, 4 000 H.-P.; reserve, 1 000 H.-P.

Initial Cost:	Total.	Per H.-P.
Boilers and Furnaces, 10 Babcock & Wilcox (500 H.-P. each)	$75 000	$15
Piping, pumps, heaters and all accessories	25 000	5
Engines; five compound condensing, 1 000 H.-P. each	100 000	20
Foundations	30 000	6
Steam plant complete	$230 000	46
Building	50 000	10
Dynamos 5 000 H.-P., each to be direct coupled compound wound and to develop 800 volts; with switchboard and all accessories	175 000	35
Power station complete ready to run	$455 000	$91

	Per day.	Per H.-P. hr.
Interest on power station, at 6% per annum, $27 300	$74 80	
Maintenance and Taxes, at 5%	62 30	
Operating Expenses:		
Coal, 48 000 H.-P.-hours per day, at $1 per net ton, and 3 lbs. per H.-P.-hour.	$72 00	$0.001500
Oil and waste	2 16	.000045
Engineers, 2 at $4	8 00	.000167
Oilers, 4 at $2	8 00	.000167
Firemen, 8 at $2	16 00	.000334
Dynamo men, 2 at $3	6 00	.000125
Superintendents, 2 at $6 and $10	16 00	.000334
Total wages	$54 00	

Total cost of operation for six hours maximum work, and twelve hours at 50%, 48 000 H.-P.-hours, and 480 train-hours, or 9 600 train-miles, or 38 400 car-miles per day	$265 19	
Total operating expenses per H.-P.-hour		$0 00553
" " train-mile		.0276
" " car-mile		.0069
" " passenger-mile, assuming that the cars carry 50% of their seating capacity		.000123

Cost:

LINE.

7½ miles of center-pole construction, including four lines of trolley wire and insulated feeders, sufficient to give a maximum drop of 20%, all complete	$40 000 00	
Block signal system for automatically stopping trains approaching within a given distance of preceding trains	12 000 00	
	$52 000 00	

	Per year.	Per day.
Interest at 6 per cent	$3 120 00	$8 54

Maintenance of Line:

One line foreman, at $2 50	$2 50		
Four line men, at $1 75	7 00		
Total wages	$9 50		
Supplies	1 00		
Total	$10 50		
		$10.50	
Running expense of line per day		19.04	
Running expense of line per train-mile		.002	
Running expense of line per car-mile		.0005	
Running expense of line per passenger-mile		.00000892	

Cost:

MOTORS.

Complete electric equipment for 60 motor cars, each including four standard 25-H.-P. single reduction water-proof motors with controlling mechanism and all accessories, including the installing of the same at Chicago and wiring of motor cars, at $5 500 per motor car	$330 000

	Per year.	Per day.
Interest at 6 per cent.	$19 800 00	$54 36
Maintenance and taxes, 10 per cent.	33 000 00	90 41

Operating Expenses:

60 drivers, 12 hours per day, at $3.	$180.00	
Grease and waste	15.00	
Running expense per day		$339 77
" " per train-mile		.0354
" " per car-mile		.0088
" " per passenger-mile		.00016

Assuming average of 50% load.

Total Initial Cost:

Central power station	$455 000 00
Line	52 000 00
Motor equipment	330 000 00
Total	$837 000 00

Motive Power Running Expenses Per Day:

Central power station	$265 19
Line	19 04
Motors	339 77
Total	$624 00

Motive Power Running Expenses Per Train-Mile:

Central power station	$0.0276
Line	.0020
Motors	.0354
Total	$0.0650

Motive Power Running Expenses Per Car-Mile:

Central power station	$0.0069
Line	.0005
Motors	.0088
Total	$0.0162

Motive Power Running Expenses Per Passenger-Mile:

Central power station	$0.000123
Line	.000009
Motors	.000160
Total	$0.000292

(*e*) The estimated cost of operating power plant, with coal at $1 per ton, 12 hours per day, would be as follows :

Coal, 110 tons	$110 00
One chief engineer, at $6 per day	6 00
Four assistant engineers, at $4 50 per day	18 00
One chief electrician, at $3 50 per day	3 50
Eight oilers, at $1 50 per day	12 00
Eight wipers, at $1 25 per day	10 00
Eight dynamo tenders, at $1 50 per day	12 00
Twenty-four firemen, at $2 per day	48 00
Two water tenders, at $1 50 per day	3 00
Twelve coal wheelers, at $1 25 per day	15 00
Ten helpers, at $1 25 per day	12 50
Water, at 1½ cents per 1000 galls	90 00
Oil, waste, etc	80 00
Total	$420 00

Question 22.—Will an electrical engineer be required to superintend the operation of this plant, or will a mechanical engineer be able to do so ?

Answers.—(*a*) For the operation of this plant a first-class mechanical engineer having experience in electric railroading, with an electrician for an assistant, will be required.

(*b*) You should engage for your service an engineer of the highest professional standing. He should have a special experience in mechanical engineering, with some knowledge of electricity. He should have as assistants a first-class mechanical engineer, to have charge of the steam plant for the power station; a good electrician, to take charge of dynamos and electrical power plant; a superintendent of motive power or master mechanic, to take charge of car and station repairs of all sorts; and a superintendent of construction, for the overhead wiring system.

(*c*) A competent and experienced mechanical engineer can soon acquire the additional knowledge necessary to fit him for the position of superintendent of this plant. No electrical engineer who did not combine a thorough knowledge of mechanical engineering would be competent to superintend this plant.

(*d*) An electrical engineer, who should also be a mechanical engineer, will be necessary to superintend the operation of the plant.

(*e*) There should be one engineer of each class, as named in estimate in Answer 21.

Question 23.—What is the best method of transmitting power from power house to motors ?

Answers.—(*a*) The best method of transmitting power from the power house to the motors is by the overhead trolley system, which will cost $150 000, including poles and all necessary copper wire.

(*b*) The overhead trolley system.

(*c*) The best method of transmitting power from the power house to the motors is by the overhead trolley system with rail return.

(*d*) The overhead trolley wire is decidedly the preferable means for conveying current to the motors. It would be fed by feeders, which would also be overhead or placed in a conduit.

(*e*) We would recommend as the best method of transmitting power from power house to motors the overhead trolley system.

Question 24.—If by the use of conduit, give estimated cost. If by the three-rail system, give cost. If by the overhead trolley system, give cost.

Answers.—(*a*) Answer contained in Answer 23.

(*b*) We would advise a strong wooden-pole construction on account of cost and insulation. The cost of poles, trolley wire, brackets (for center pole construction, which would probably be the best, if the suburban tracks are side by side), line appliances, track wire and labor in erecting, would be not far from $2 500 to $3 000 per mile of double track. The cost of feed wire would be very large and could not be given without knowing the location of the power station. It will be, approximately, $15 000 to $20 000 per mile of double track for a railroad system 15 miles in length, with power station in the center, operating 50 trains, requiring 100 average horse-power each.

(*c*) We estimate the quantity of copper required for conductors at 500 000 lbs. for the overhead conductors, and 250 000 lbs. for the rail work. At 15 cents a pound for copper this would make $75 000 for the overhead work, and $37 500 for the rail work. Copper is at the present time selling at a little less than this, being lower than it has been for a number of years. The cost of construction and material other than copper for the single line of poles required between the two lines of rails we estimate at about $10 000.

(*d*) The cost of the trolley wire with center-pole construction, together with necessary feeders, cut-out switches, lightning arresters, and all of the necessary apparatus to operate the line efficiently and safely, would be $1 000 per running train. Assuming that 40 trains would be running, it would require $40 000 for line construction.

(*e*) The cost of this overhead system could not be determined until line has been laid out, as the extra service would call for special line material, the style of which could only be determined by taking into consideration all of the conditions to be met.

Question 25.—If the overhead trolley system is used, what is the best method for supporting wire, and how far should the supports be apart?

Answers.—(*a*) The best method of supporting the wires in this particular case is by bracket suspension, and poles should be not more than 125 ft. apart.

(*b*) As before stated, we would advise wooden poles, with side brackets, extending over the side of each track, placed about 100 ft. apart.

(*c*) With overhead trolley system, the best method of supporting wires is by posts set midway between the two lines of rails, these posts being provided with iron bracket arms, extending 18 or 20 ins. on each side of the posts, trolley wire to be supported by proper clamps from the extremities of the bracket arms. Poles should be fifty to the mile, which would bring them about 100 ft. apart.

(*d*) Wooden poles 100 ft. apart placed between the two tracks, with a cross-bar reaching out each way to the center of each track, from the ends of which arms the trolley wires are supported from insulators, would be the preferable method of construction.

(*e*) For the overhead trolley system we would recommend the center-pole construction as being the best for the system under consideration.

Question 26.—(1) What size should trolley wires be? (2) What size should feed wires be, and what distance apart should they feed into the trolley wire? (3) Give probable cost of repairs and maintenance of three systems.

Answers.—(*a*) (1) The trolley wires will be No. 00.

(2) The size of the feed wires to be determined after a more complete examination of the nature of the ground, and they should feed in the trolley wire ½ mile apart.

(3) The overhead trolley system will require practically no outlay for repairs, if put up properly.

(*b*) (1) Trolley wires should be No. 00 or No. 000, B. & S. gauge.

(2) There would be a number of insulated feed wires not exceeding No. 0000 in size. They should feed into the trolley wire at intervals of not over 500 ft.

(3) The overhead system should be maintained at a cost for labor and material of less than 5% of the original cost per year.

(*c*) (1) Trolley wire should be ½ in. in diameter of hard-drawn copper.

(2) Parallel conductors connected to the trolley wires at every post, in circuit with the trolley wires, would be employed, these conductors varying in capacity, according to the current to be conveyed.

(3) The cost to maintain and keep in repair the system of overhead wires and poles would not be very heavy. If properly constructed in the first place, the annual expenditure for maintenance would be a smaller percentage of the cost than that of maintaining a single line of track on the railroad.

(*d*) No. 00 wires should be used for trolley wires and about 60 000 ft. of No. 0000 wires for feeders. They should feed in at sections corresponding with the signal blocks and should be controlled by switches at the central station and also at the line, so that the current could be cut off from any part of the line either automatically by the block signal or at the will of the officials of the road. To repair this overhead system would require a gang of five men; one at $2 50 per day, and four at $1 75, making a total of $9 50 for wages, and $1 for supplies per day, making a total of $10 50 per day for maintenance of line.

(*e*) The size and style of trolley wire will have to be determined after plant is laid out. It is probable that special means for making the trolley contact would have to be provided. Feed wires * * * should feed into the trolley wire about every 500 ft. This distance, however, will have to be determined with reference to the size and style of trolley conductor finally determined upon. We are unable to give cost of repairs on such an overhead system until all the details have been worked out. If properly put in, it should not exceed 3% of the first cost.

Question 27.—What percentage of extra equipment will be needed to provide for repairs?

Answers.—(*a*) We would advise that 10% of the regulating devices for the motors, armatures, field coils, commutators, brush holders, gears and trolleys and bearings be kept in stock for repairs.

(*b*) You would need about 25% in the power station to provide for repairs and contingencies of traffic, and you should provide about 10% reserve of car equipment for repairs only.

(*c*) Ten per cent. extra equipment would be sufficient to provide for repairs.

(*d*) There should be allowed an extra equipment of motors of 10% of the whole number, and it would be necessary to keep in stock about $2 000 worth of duplicate supplies in the shape of gears, brasses, armatures, etc.

(*e*) About 15% extra equipment will be required to provide for repairs. The percentage of extra equipment depends very largely upon the superintendence and care given the motor cars.

Question 28.—What will be necessary in the way of repair shop, plant and forces to repair motors?

Answers.—(*a*) A small repair shop, with the following tools will be required: One hydraulic wheel press for pressing wheels on end of the axles; one engine lathe large enough to take in armature axle for turning down commutator and for repairing armatures in general; four winding lathes for winding armatures, and one lathe for winding field coils, in case you decide to wind your own coils; one small engine lathe for making minor repairs to regulating devices and a few vises

for bench work. The repair shop should also have the necessary soldering tools for repair work. One complete blacksmith shop outfit, one line wagon and line tools, blocks, tackle, etc. Total number of men in repair shop, about six.

(*b*) If you adopt gearless motors and slow-speed generators with ring armatures, you will need a small machine shop, covering an area of perhaps 50 x 30 ft., equipped with a few lathes, two or three planers, a radial drill, etc. Your force would consist of a half-dozen winders, who need not be skilled workmen, four or five good mechanics and a foreman. Your stock would consist of brasses, Babbitt metal, commutators and commutator bars, and three or four sizes of copper wire. The above is on the supposition that the heavy machine repairs on engines, etc., will be done in your locomotive repair shops, and repairs on car bodies and trucks in your car shops.

(*c*) The repair shop will call for an outlay in tools and employment of forces of no more than that necessary for a steam equipment of the same capacity. It is probable that this item of expense will fall considerably below that of a steam plant in the course of several years' operation, but for a year or two it will be safe to place the two systems on a level in this particular.

(*d*) A machine shop for ten mechanics, with ten lathes, one drill and one blacksmith's equipment, would be necessary to keep the motors in repair. There will also be room for a car repair shop for ten motor cars. This will require a space of about 70 x 200 ft.

(*e*) The tools required for repair shop will be about as follows: One 30-in. lathe, one medium-size drill press, one press for pressing commutators off and on, one gear cutter, one milling machine, one complete blacksmith shop, one forge.

The necessary help would be about ten men, at $2 per day, and this repair shop could be looked after by the superintendent of the line, assisted by the chief electrician.

Question 29.—In considering the question of the advisability of running more cars of less weight and capacity, is it desirable to construct a separate electric locomotive carrying no passengers, or a separate motor room in each end of the car, with a limited passenger capacity between the two motors, for the purpose of having larger drive wheels? Or would you recommend the present style of motor? Give prices of the three different kinds of motors.

Answers.—(*a*) In our opinion, it is desirable to construct separate locomotives carrying no passengers. These locomotives to be equipped with two motors each. Diameter of driving wheels to be 42 ins.

(*b*) As before stated, it would not be difficult to build a motor car of the type specified to handle three instead of two double-truck trail cars, all heavily loaded. We would not advise building a separate electric locomotive which would carry no passengers, because of

the fact that the controlling mechanism in electric motor cars is simple, and requires very little room as compared with that of a steam locomotive. Moreover, by making the motor car carry passengers, the weight of the latter is available for traction, and, as this car would be a smoking car, it would nearly always be well filled. We have already indicated the price of passenger motor cars. The price of an electric locomotive would not be greatly different, but would be more, rather than less.

(*c*) We think that it would not be desirable to construct a separate electric locomotive, carrying no passengers, but that the motor car should constitute one of the three passenger cars. We think the advantages lie in favor of trains with three cars, including the motor car, of medium weight and capacity. Two or three trains could be loaded at the same time, and, when loaded, could get under way promptly. No room would be taken up in the motor cars by the motor mechanism, and this car body could be the same in construction and capacity as those of the trailers.

(*d*) We do not think anything would be gained by running more cars of less weight and capacity. The trains could not well be operated nearer together than one a minute, and four-car or five-car trains could be operated about as well on this headway as a two-car or three-car train. Should the line be eventually used for suburban service, with frequent stops, the number of cars per train would have to be reduced, probably to three, while the central station power would remain the same. This is to allow for the greater power required to accelerate after the frequent stops. We would not advise partitioning off part of the motor car, as the whole of it might be utilized for passengers, but there would have to be a vestibule for the driver, in case the cars had no platform. The wheels would be 36 ins. in diameter, so that they would not come within the car body. In regard to the alternative of the separate locomotive, there is to be said—such a motor to do this work would be our 16-ton locomotive * * * equipped with two gearless motors. The cost of this would be $12 000, and it would be able to make greater speed than the gear motor above referred to—40 miles an hour, if necessary. These motors have not yet been built, but are now in process of construction, and would probably operate the road as efficiently as the single-reduction motor. The chief difficulty would be in producing a new type of motor in time for the World's Fair, especially as such a great number of them would be required.

(*e*) We think that your experience in handling passengers should enable you to give a much more accurate estimate of these questions than we are able to make. We are in favor of using motor cars instead of electric locomotives, since in the case of the motor cars the weight of the passengers with the heavy car necessary to carry them is

available for traction. We would also recommend the present style of motor.

Question 30.—How much will it cost to operate this system per mile, per motor and per car, and also per passenger per mile?

Answers.—(*a*) The cost of operating forty 30-ton electric locomotives will be from 9 to 10 cents per mile per locomotive, including all labor and repairs.

(*b*) You can operate at about 12½ cents per car-mile, or 35 cents per train-mile. If the traffic to the World's Fair is as great as is anticipated, you can undoubtedly operate at from 2 to 2½ cents per passenger. We shall be pleased to give detailed and convincing estimates of the cost of operation, if desired, and at the proper time.

(*c*) To figure the cost per mile per motor and per car and also per passenger per mile would involve a considerable amount of calculation. We will make this calculation later and submit it when made.

(*d*) Answered in No. 21.

(*e*) We are unable to give an accurate answer to this question at this time. Various factors enter into this that require considerable time to consider.

Question 31.—Is there any electric line in operation similar to the one under consideration?

Answers.—(*a*) There is a similar line on a smaller scale equipped by the Westinghouse Company now in operation at Sioux City, Ia. On this line, however, the motor car carries passengers. The road has 4% to 5% grades, with sharp curves.

(*b*) Not precisely, but, as before stated, we are meeting conditions in service of street car work which vary only in slight degree from those under consideration.

(*c*) There is no electric line in operation similar to the one under consideration.

(*d*) The line running from Brooklyn to Coney Island operating trains of three cars at a speed of 15 to 20 miles per hour and carrying 250 passengers per train is the nearest approach to the conditions given at Chicago. The West End road in Boston, operating from 300 cars over about 100 miles of line, is also a comparable instance. The West End is now building two large stations, the larger of which will have a capacity of 27 000 H.-P. They are now operating on one circuit about 3 000 H.-P.

(*e*) We are not familiar with any electric line that is similar to the one under construction.

Question 32.—What is the longest line now operated, and the greatest number of cars that are operated with one motor?

Answers.—(*a*) The longest line now in operation with one motor car and three trailers is in Sioux City, Ia.

(*b*) One of the longest lines now operated is probably that between St. Paul and Minneapolis, a distance of about 25 miles; a speed of 20 to 25 miles per hour is attained on this road, we believe. One of the most severe conditions of operation that we know of is found at Jamestown, N. Y., whose street railway is operated by our motors. The motor cars have 18-ft. bodies, exclusive of platforms, which are vestibuled, making a car which weighs, with motors, between 6 and 7 tons, without loads. These cars are equipped with two 15-H.-P. double-reduction motors. The summer traffic is very heavy, and the motor cars draw in regular service one trail car, both heavily loaded, over a succession of grades reaching a maximum of 10% and having a number of sharp reverse curves therein. During the past summer there have been occasions when the railway company has been forced to draw three trail cars with one of these 30-H.-P. motor cars, making four in all, over some of the lighter grades of the road.

(*c*) There are many lines of electric cars, 8 miles in length, in operation at present, and two cars are frequently operated by a single motor car.

(*d*) Accompanying this paper is data sufficient to answer this question. (Answer 31.)

(*e*) The longest line with which we are familiar that is operated from one station is 13 miles in length. We believe there are longer lines, but in general they are operated from more than one station.

Question 33.—Give capacity per hour, speed and time between trains?

Answers.—(*a*) See page 158.

(*b*) We have no information with which to reply to this question.

(*c*) The electric lines now in operation are ordinary street car lines.

(*d*) The greatest traffic handled by an electric road with which we are familiar is the West End, which handles on its electric cars as many as 15 000 passengers per hour. The cars run on some parts of the line with less than 20 seconds headway and are often operated at a speed of 18 miles an hour.

(*e*) A train could be started every minute, and, supposing each train to carry 336 passengers, this would make about 20 000 passengers per hour. To do this, however, would necessitate the construction of three platforms from which passengers could enter cars at both sides at the same time. We would suggest that the train drop its passengers at one platform and then move forward to another platform where passengers could enter cars. By having three platforms from which trains would leave, it would give three minutes for a train to become loaded. The speed on the line could be arranged at anywhere between 20 to 25 miles an hour. The time between trains would be one minute. It would possibly be better to make the road four tracks wide with switches at every half mile, so that in case of accident to a

train the train following could be switched on to the other track for the same direction, and thus avoid delay. The road, of course, would have to be equipped with the block system, or something similar, so that "end on" collisions would be avoided.

Question 34.—Is it possible and practicable to carry from 20 000 to 30 000 passengers per hour with electric power under the conditions named?

Answers.—(*a*) There is not the slightest doubt but that 20 000 to 30 000 passengers can be carried from the Lake Front Park, in the city of Chicago, to the Columbian Exposition by electric power under the above conditions.

(*b*) Yes, without question.

(*c*) We think it possible and practicable to carry 20 000 passengers per hour, or more, from Lake Street to Jackson Park by electric power under the conditions named. First-class terminal facilities would need to be provided in order to reach the above figure.

(*d*) It is quite possible and practicable to carry 20 000 and, probably, 30 000 passengers per hour with the electric motors under the conditions named.

(*e*) The statements made in Answer 33 apply as well in this.

Question 35.—Is it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893?

Answers.—(*a*) It is possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893.

(*b*) Yes. We could install three such plants with our present factory facilities.

(*c*) We consider it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893.

(*d*) It is quite possible and practicable to have the plant in operation by March 1st, 1893, especially if standard motors are used and the contract given before April 1st, 1892.

(*e*) We think it possible and practical to supply the apparatus for this plant, ready for full and complete operation, by March 1st, 1893.

Question 36.—How soon will it be necessary to award the contract for the above plant in order to have the line ready for operation by March 1st, 1893?

Answers.—(*a*) It will be necessary to award the contract for the above plant on or before March 1st, 1892, in order to have it in operation by March 1st, 1893.

(*b*) The contract should be placed by March 1st, 1892, in order to be certain of completion at the specific time.

(*c*) In order to complete this plant by March 1st, 1893, contracts for the principal portions of the work should be made very soon.

(*d*) Before April 1st, 1892.

(*e*) It would be necessary to award the contract at the earliest possible date, not later than March 1st, 1892, since the apparatus should be put in operation by installments, and the various officers become familiar with their duties before the system is worked to its full capacity.

Question 37.—Would your company guarantee, on your own specifications and at an agreed price, the successful installation and operation of this plant by March 1st, 1893, with guaranteed capacity of 20 000 people per hour in one direction? (It is understood that whenever the capacity of 20 000 people per hour is mentioned, it is in one direction.)

Answers.—(*a*) Yes; provided you make the necessary arrangements to load the passengers on and off the cars.

(*b*) We would make such a guarantee under heavy penalties of non-fulfilment.

(*c*) In our opinion, the units above indicated. that is, an engine, with boilers and generator and one train of cars, could be placed in operation by June 1st, this year. This train could be operated over a sufficient length of your track to fully determine all questions of speed, power and capacity. Our company would probably be willing to undertake the construction of the electrical apparatus required within the time specified, conditioned on the approval of the operation of the single train, above mentioned, at as early a date as practicable. Our preference would be not to have the responsibility of the contract for the steam plant, nor for the erection of the conducting wires; there are parties who make this line of work specialties, and if we were called upon to assume the whole contract, we should employ such parties to do such portions of the work.

(*d*) Yes.

(*e*) No answer.

Question 38.—Do you recommend horizontal or upright engines?

Answers.—(*a*) We recommend engines of the Corliss type.

(*b*) With more time in which to act we would probably be willing to recommend vertical engines, but they have not yet stood the test of as long experience as have horizontal engines, and, as it is most important that experimental work be avoided, we recommend horizontal Corliss engines, as stated above.

(*c*) Our preference would be for horizonal engines.

(*d*) No answer.

(*e*) We would recommend vertical engines, as before stated.

Question 39.—What is the best form of connection between engines and generators, belt or countershaft?

Answers.—(*a*) In our opinion, the best forms of connection between the engine and dynamo are ropes or belts, doing away with all countershafting.

(*b*) Both should be avoided and direct connection made between the dynamos and engines. In the latest and most improved engineering practice very slow-speed dynamos have been developed, corresponding to the speed of the engine used. If it is necessary to use transmission by either belt or countershaft, belts should be employed without question. Countershafts should be avoided under all circumstances.

(*c*) Our preference would be for direct connection between the engine and generator, not using either belt or countershaft.

(*d*) No answer.

(*e*) We would recommend direct-driven dynamos without belt or countershaft.

Question 40.—Are high or low speeds preferable, and about how many revolutions per minute?

Answers.—(*a*) Low speeds are preferable—300 revolutions per minute.

(*b*) Low speeds—about 100 revolutions per minute.

(*c*) Our preference would be for a medium speed, say 90 to 100 revolutions per minute.

(*d*) No answer.

(*e*) We would consider moderately high-speed engines preferable. In the engines before mentioned the speed would be 100 revolutions per minute, with a piston speed of 600 ft. per minute.

Question 41.—What is the proper size of wheels for motors and for trailers?

Answers.—(*a*) The proper size of wheel for the locomotive is 42 ins., and for the trailers the same as now on the suburban cars—33 ins. diameter.

(*b*) For motor cars, 42-in. wheels; for trail cars, bogie trucks, 36-in. wheels.

(*c*) We should say that the size of the car wheels on motors and trailers should be about 30 ins. diameter.

(*d*) No answer.

(*e*) We would recommend for the proper size of wheels 48 ins. for motor cars and trailers.

Question 42.—What will be the percentage of loss in power between the steam engine and the motor ?

Answers.—(*a*) The efficiency of the system will be as follows: Efficiency of engine, 85%; efficiency of dynamos, 94%; efficiency of line, 80%; efficiency of motors, 90 per cent.

(*b*) Between the cylinder of the engine and the pulley of the dynamo there will be a loss from engine friction of about 15 to 20 per cent. There will be a total loss in the dynamo of about 6% in a 500-H.-P. generator, and an average loss between the station and the motors of about 15 per cent. There will be an average loss of about 20% in

the motors. The general efficiency of the system will, therefore, be slightly over 50 per cent.

(*c*) The percentage of loss in power between the steam engine and motor will be about 25%, to which must be added the loss in the motor itself of about 15 per cent. The total loss of energy between the shaft of the engine and the rails will probably approximate 50 per cent.

(*d*) No answer.

(*e*) The approximate loss between the steam engine and motor would be about 15 per cent. This is about equally divided between the dynamos and line.

Question 43.—What is the lowest practicable radius for curves in terminal loops ?

Answers.—(*a*) The curves on the terminal loop should not be less than 100 ft. radius.

(*b*) There will be power in the motors sufficient to carry a three-car train around a 50-ft. circle, and there will be no mechanical difficulties in the way. It is, of course, desirable to have a much larger circle, up to 200 or 300 ft.

(*c*) We think the radius of curves in the terminal loops should not be less than 100 ft., and, of course, it would be better to have the curves of a still greater radius than that.

(*d*) No answer.

(*e*) We think your experience would be a surer guide as to the best practice in the matter of curves, but would suggest, however, that the curves be not less than 150 ft. in radius.

Question 44.—What radius of curvature on the loops, on the supposition that the trains will be empty in going around the loops, and run at a speed of about 5 miles an hour, will make the resistance on the loops equivalent to a speed of about 20 miles an hour on the straight portion of the line ?

Answers.—(*a*) Curves with a radius of about 100 ft.

(*b*) No answer.

(*c*) We have no sufficient data for estimating what curvature on the loops would make the resistance on the loops equivalent to a speed of 20 miles an hour on the straight portion of the line.

(*d*) No answer.

(*e*) The answer to this question depends upon such a number of variables that we are unable to give an accurate answer. Under ordinary conditions of road this varies considerably with the speed the train had when it took the curve, and the rate of acceleration on the curve.

Question 45.—Can air be applied to closing and opening side car doors on passenger trains?

Answers.—(*a*) No answer.

(*b*) Yes, if desired, but, as before stated, we would strongly advise end entrances for this class of travel.

(*c*) We do not feel qualified, without taking further time for investigation, to pass on the question as to the best method of opening and closing the side car doors on passenger trains. We know of no reason, however, why air could not be applied to the opening and closing of these doors.

(*d*) No answer.

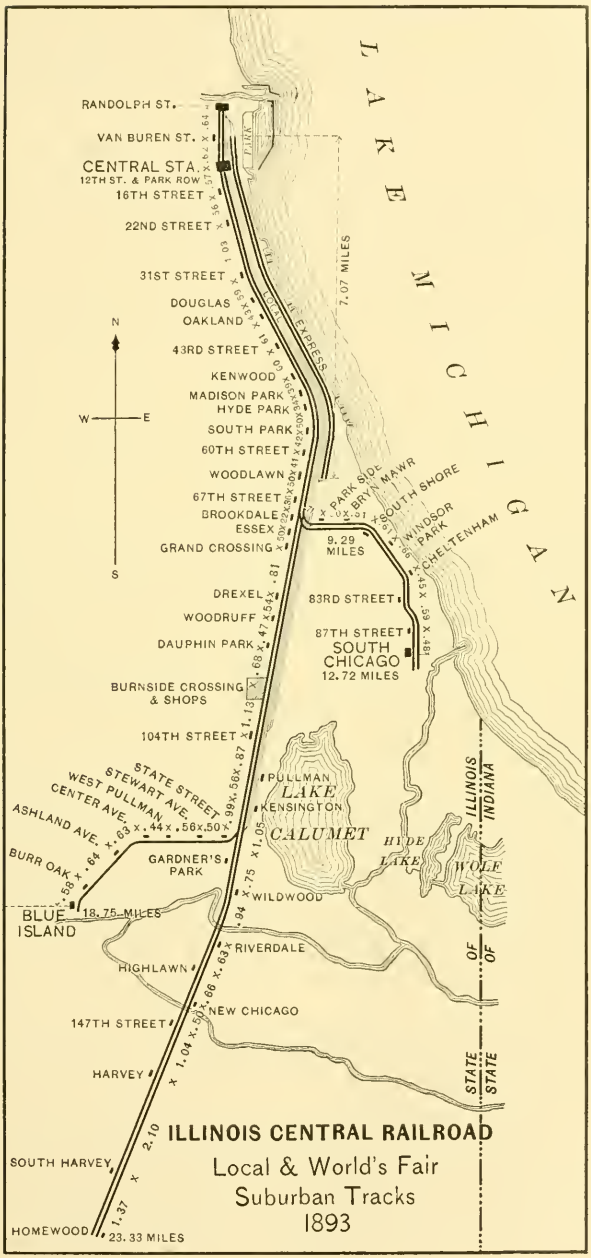
(*e*) Air may be readily applied to open and close the side doors of passenger trains, but we would consider this would be objectionable in trains moving at such a high rate of speed, as passengers would hardly become seated before the train left the station, and with an automatic arrangement of this kind there would, no doubt, be considerable injury to the passengers from the doors catching their clothing and limbs.

In addition the author personally visited the works of various electric manufacturing companies in the United States, and also discussed at length the different phases of the problem with electric and mechanical experts. The answers to the preceding questions were furnished after careful and mature deliberation on the part of the electric companies.

In order to illustrate the situation as to track arrangements, Fig. 1 shows the lay-out of the tracks used exclusively by the Illinois Central Railroad for its suburban service, with its different suburban stations. The two heavy black lines on the left of the diagram indicate the two tracks set apart for the exclusive World's Fair business, and the remaining heavy lines show the tracks devoted to the regular suburban service.

In regard to the practicability of handling a large number of people by electric power between the site of the Exposition and Van Buren Street, in the city of Chicago, the author was satisfied it was both possible and practicable to handle as large a number as 20 000 persons per hour between the points mentioned by electric power. He was also satisfied that it was possible and practicable to handle the entire suburban business of the Illinois Central Railroad between Randolph Street and Homewood, South Chicago and Blue Island by electric motive power.

While it would seem in a general way to be self-evident that it would be more economical to generate power at a central station and transmit it to motors by electricity, than to maintain and operate separate and distinct steam plants (locomotives) to propel each individual transportation unit, the practical results so far obtained from a com-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KENWOOD
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HYDE PARK
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WOODLAWN
67TH STREET
BROOKDALE
ESSEX
GRAND CROSSING
DREXEL
WOODRUFF
DAUPHIN PARK
BURNSIDE CROSSING & SHOPS
104TH STREET
STATE STREET
STEWART AVE.
WEST PULLMAN
CENTER AVE.
ASHLAND AVE.
BURR OAK
BLUE ISLAND
18.75 MILES
GARDNER'S PARK
WILDWOOD
RIVERDALE
HIGHLAWN
147TH STREET
NEW CHICAGO
HARVEY
SOUTH HARVEY
HOMEWOOD
23.33 MILES
7.07 MILES
PARK SIDE
BRYN MAWR
SOUTH SHORE
WINDSOR PARK
CHELTENHAM
9.29 MILES
83RD STREET
87TH STREET
SOUTH CHICAGO
12.72 MILES
PULLMAN
LAKE
KENSINGTON
CALUMET
HYDE LAKE
WOLF LAKE
ILLINOIS
INDIANA
STATE OF
STATE OF
ILLINOIS CENTRAL RAILROAD
Local & World's Fair
Suburban Tracks
1893

FIG. 1.

parison of the cost of operating steam power as applied to steam railroads, and the use of electric power as applied to street car lines, does not bear out the theory. This, however, may be partially accounted for as follows:

In the application of electricity as a motive power, which has only been in use for a few years, and then only to operate street car lines, the engineers giving this matter their attention have been enthusiastic electricians; they have seldom been practical or expert mechanics.

Electricity as a motive power has only been used under the most unfavorable conditions, to operate street car lines with crude motors, poor track complicated with sharp curvature, steep grades and operated by comparatively inexperienced and inefficient men, mule-drivers having frequently been converted into electric motormen.

In considering the present problem, however, the application would be made on first-class standard gauge track, with practically no grade and very slight curvature, except at terminal points; stops would be infrequent, the most improved motors would be used and placed in charge of intelligent and disciplined men, rendering the conditions under which the electric power would be used the most favorable that have ever existed. There was, at the date of this examination, no electric line operated under such favorable conditions with which comparisons could be made, consequently no estimate of the cost of operating an electric system under these conditions could be made more than approximately. In the then existing electric street railway practice operating expenses amounted to 2 to $3\frac{1}{2}$ cents per passenger carried. This was a very favorable showing, however, considering the unfavorable conditions—the use of geared motors, bad roadbed, inefficient management, and the fact that all street railway lines ran large numbers of cars containing but few passengers, some of the larger systems having non-paying branches upon which traffic was very light, which had a tendency to increase the cost per passenger.

There were also several considerations in favor of the adoption of electric power which could not be reduced to dollars and cents, viz.:

First.—The ability to run more transportation units in the suburban service at less expense per unit, than by the use of steam, thereby changing the present steam suburban service from a time

card to a street car basis, doing away with the necessity of passengers waiting for schedule trains and thereby building up and increasing the suburban service.

Second.—The advantage of not being required to stop for coal and water.

Third.—The absence of smoke and dirt.

Fourth.—The possibility of the road being required to use anthracite coal for engines inside the city limits of Chicago, increasing the cost of fuel at least five-fold and largely adding to the cost of steam service, which would of course have a tendency to render the use of electricity economical.

Analyzing the figures obtained from the electric companies, it was estimated that the necessary plant and equipment for operating express trains between the city and the Exposition grounds would cost $1 200 000, divided approximately as follows:

Power plant	$600 000
Wiring and line plant	325 000
Motors in service, extra motors and motor parts	260 000
Repair shop for motors, with necessary machinery and appliances	15 000
	$1 200 000

The annual cost of operation was estimated as follows:

Interest on plant at 5%	$60 000
Operating power plant	85 000
Operation and repairs of motors	101 700
Maintenance of line and wire system	10 000
	$256 700

These estimates were based upon furnishing electric transportation service for the express trains between the city and the Exposition during the Fair period, operating the regular suburban service during the same period by steam, and at the close of the Exposition extending the application of electric power to the entire suburban system. The foregoing estimate would furnish the same maximum capacity per hour as the existing service.

Comparing the estimated annual expense of the electric application with the actual cost of the steam service for the year ending June 30th, 1891, shows the former to be $144 200 in excess of steam for motive power alone. While it is true that trains could be run at more frequent intervals at the same cost, there would, of course, be some additional expense for an increased number of trainmen, etc.; still the electric application would give an increased capacity during a part of the day, which might stimulate and add to the suburban business. In order to justify the extra outlay, however, there would have to be an increase in the suburban business over the year ending June 30th, 1891, of approximately 25 per cent. This would be necessary to offset the extra cost of making the electrical application.

In considering the question of steam versus electricity for the business due to the Exposition, it was found that it would be much more economical to use steam power for this service, and that the equipment necessary for it could afterwards be used for other purposes. It was deemed that it would be advisable, particularly during the busy hours of the morning and evening, to run large units of transportation, as the time consumed in loading and unloading a train would be the same regardless of the length of the train, due to the system which had been decided upon of loading and unloading trains to and from high platforms directly into and out of the sides of the cars, and which afterwards proved so successful; and that it would be safer and more economical to carry a great number of people on heavier trains and run them greater distances apart, rather than have a large number of smaller trains running at short intervals of time. No difficulty was apprehended in running trains of ten or twelve cars each, with a capacity of 1 000 passengers per train, at intervals of three minutes, which would give a capacity of 20 000 passengers per hour. The history of the Exposition more than bore out this theory, as on one night during the hour of heaviest travel, 45 trains were dispatched from the Terminal Station in the Exposition ground, carrying from 1 000 to 1 200 persons each. This was the maximum number of passengers carried in the shortest period of time, and more than exceeded previous expectations.

A factor also in this connection was the fact that it would require from 45 minutes to one hour to make the trip from the Exposition to the heart of the city by the existing cable lines, and at least 30 minutes

by the elevated road; that if electric power was used on the Illinois Central, the tracks would be occupied by such a large number of small units of transportation that it would not be feasible to run them at the speed which would be possible in the handling of large units of transportation by steam at less frequent intervals; and that it would be possible to handle trains between the heart of the city and the Exposition grounds by steam in less than 20 minutes, which would have a tendency to increase the patronage of the Illinois Central line. Experience afterwards proved the correctness of this view, as the average time of the express trains between Van Buren Street and the Midway Plaisance was approximately 12 minutes.

It was therefore decided that while the application of electricity as a motive power might be practicable, it would not be the economical thing to do, and that it was specially undesirable in providing for the large business contemplated during the holding of the Exposition to introduce any elements of uncertainty. The results which could be obtained by the use of steam power were known and definite, both as to economy, efficiency and speed, and it was not considered advisable or economical to adopt electric power for this service.

Deciding the second proposition in the negative rendered it unnecessary to consider at any length the question of appliances except incidentally in determining the question of the economy of electrical application.

It was considered by the author at that time, that, as the use of electric power was rapidly advancing, results would be obtained in the near future which would render its adoption practicable and economical, particularly for terminal and suburban lines.

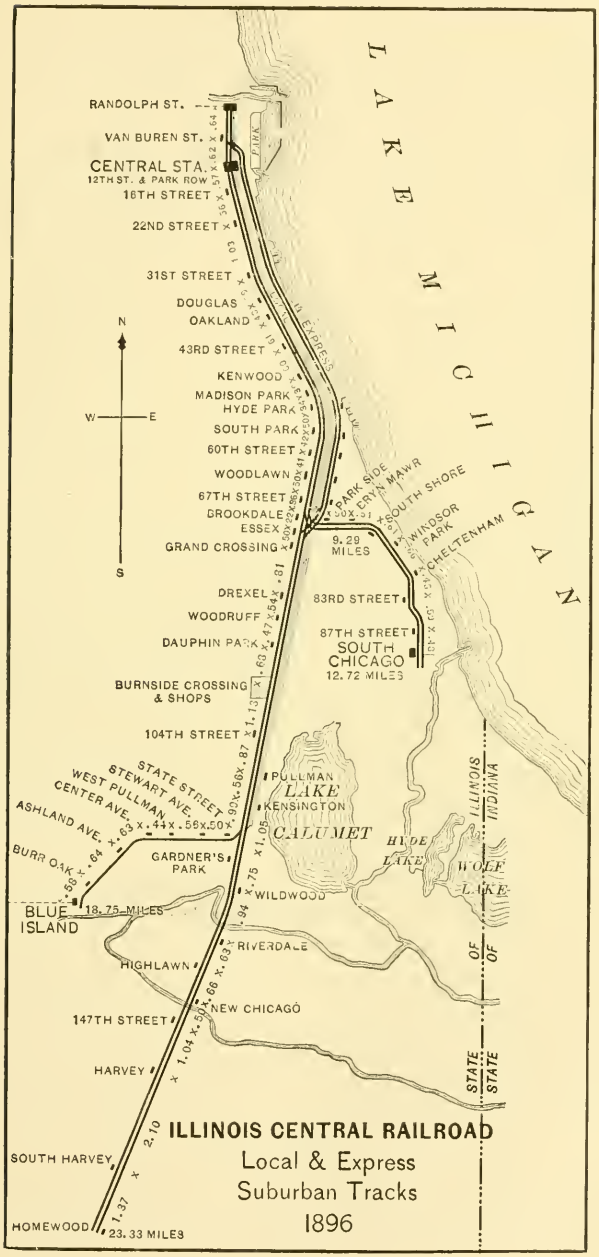
At the time of this investigation, five years ago, while success had been obtained in the adaptation of electricity to street railway systems and small units of transportation over short distances, its application to the larger requirements of terminal and suburban service, which had heretofore been performed by steam power, was yet experimental. The requirements of the Illinois Central service were approximately ten times in excess of the then existing practice, and the adoption of electric power for Illinois Central business, either for World's Fair or the regular suburban traffic, would have been largely experimental and the estimates of the cost of maintenance and operation only approximate.

In discussing verbally the question of appliances, much stress was laid by the representatives of the various electric companies upon the speedy adoption of what is known as the gearless motor; and while they expressed every confidence in the gearless motors which they were manufacturing and had in process of perfecting, the written propositions of some of the companies contemplated the use of single-reduction motors.

The statements of the various electric companies differed largely as to the expense of the application of electric power. For the same capacity their figures varied from $375 000 to $1 200 000. Their opinions of the amount of horse-power needed ranged from 5 000 to 18 000 H.-P. The differences in the estimated cost of operating the power plant per day ran from $232 to $616. In their estimates of the amount of fuel needed per horse-power per hour, the variation is from 2 lbs. to 3½ lbs. of coal. The figures on motors ranged from $7 500 to $10 500; and the cost of operation and repairs of motors per day from $286 to $430. There was a variation in the estimates of the cost of trolley lines and feed wires of from $40 000 to $172 000, and variation in the estimate of repairs to same and other line expenses from nothing to $23 50 per day.

During the five years since this problem was considered, great advances have, of course, been made in the application of electric power, and the cost of appliances has been largely reduced. More certain and reliable data is also doubtless available as to its economy and the cost of maintaining and operating electric power. A number of steam railroad companies are seriously considering the question of replacing their locomotive engines by electric motors for suburban business, and it seems that the general question opens up a wide field for discussion, the results of which should bring into the *Transactions* of the Society a large amount of valuable matter in the line of electric engineering.

Comparing the use of steam and electricity as motive powers, as a general principle it may be stated that electricity is more desirable and economical for handling a large number of small transportation units at frequent intervals over short distances; whereas, steam power is more desirable and economical for handling large units of transportation at high speeds, at infrequent intervals and over long distances. In treating of special applications, it may be further said that the increase in the use of electricity will grow along these general lines.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NEW CHICAGO
HARVEY
SOUTH HARVEY
HOMEWOOD
23.33 MILES
STATE OF ILLINOIS
STATE OF INDIANA
ILLINOIS CENTRAL RAILROAD
Local & Express
Suburban Tracks
1896

FIG. 2.

Where the substitution of electricity for steam is considered, the question of the disposition of the abandoned steam plants and the amount of money invested therein becomes a factor.

This matter of applying electric power to its suburban service is again under consideration by the Illinois Central Railroad. Fig. 2 is a diagram showing the tracks now devoted exclusively to this service in the city of Chicago. The change from the conditions that existed in 1891 consists in the use of the two west tracks between Randolph Street and Grand Crossing for the local suburban business, trains between these points being so operated as to give a continuous service with trains 20 minutes apart during the hours of light traffic, and from 5 to 10 minutes apart during the busy hours of morning and evening. Ordinarily, these local trains only run as far south as Sixty-third Street, the suburban business from the South Chicago branch, the Blue Island branch, and from the main line at Homewood, Harvey, Kensington, etc., being diverted at Sixty-seventh Street to two tracks along the east side of the right of way, and after making local stops at Sixty-third, Sixtieth, Fifty-seventh and Fifty-third Streets, running from there without stop to Van Buren and Randolph Streets in the city. This forms what is known as the express suburban service. Trains run 20 minutes apart during the day, and 10 minutes apart in the morning and evening, when the traffic is heaviest. The location of these express suburban tracks is such that they are not cut by facing-point switches north of Sixty-seventh Street except at two places; at one of these a Wharton safety switch is used and the other is controlled and protected by the interlocking plant at Forty-third Street. No street crossings exist between these points.

The problem now under consideration is the practicability, desirability and economy of adopting electricity as a motive power for this entire suburban system. Under this general head come minor problems as to the partial adoption of electric power for either the regular or express suburban service or parts thereof, as to the proper location and arrangement of a power house and plant; what system shall be used for the transmission of power; the size of transportation units; whether independent motors of large power should be used to haul long trains of trailers, or whether small transportation units run at more frequent intervals should be adopted, using the motors for carrying passengers.

Following is the present amount of equipment assigned to this service: Twenty-one engines, having 16 x 22-in. cylinders, 49½-in. drivers, four-wheel; weight, 117 000 lbs. Two engines, having 18 x 22-in. cylinders, 49½-in. drivers, six-wheel; weight, 160 000 lbs. Ten engines,

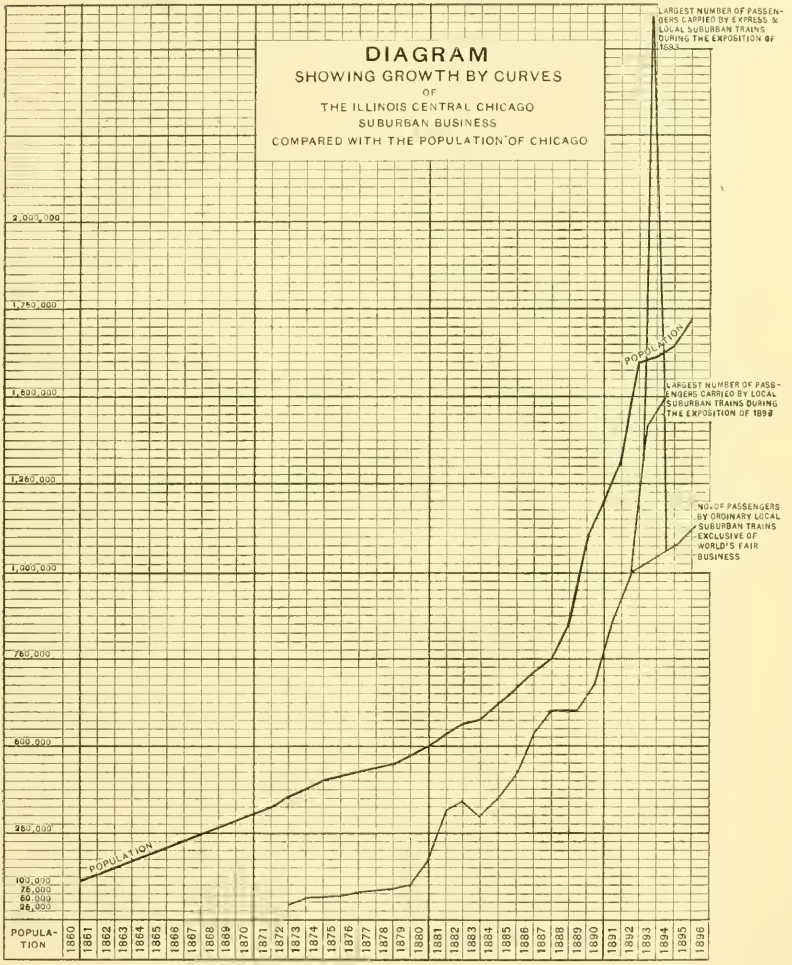

FIG. 3.

having 17 x 24-in. cylinders, 49½-in. drivers, four-wheel; weight, 166 000 lbs. In all, 33 engines valued at $8 500 each; total value, $280 000. The suburban coaches in use number 162; they are 45 ft. long and average a seating capacity of 54 persons; value, complete,

with steam heat and Pintsch gas, $3 500 each; total value, $567 000. The grand total value of suburban equipment amounts to $847 500.

Fig. 3 is a diagram which shows the increase in the population of the city of Chicago from 1860 to date; also in finer black lines the ratio of increase in Illinois Central suburban business by years. The figures on the left-hand margin show the population, without any reference to the number of passengers carried by the Illinois Central suburban trains. The actual number of passengers carried is not indicated, but simply the ratio of increase year by year. From 1892 to 1894, the lower line shows the suburban business as it would have been unaffected by the Exposition. The lines extending upwards show the proportionate increase in the business due to the Exposition on both the local and express services. The rate of increase in the city's population and the Illinois Central suburban business show a diminished ratio in 1893 and 1894, which was due, so far as the population is concerned, to financial conditions in those years, and as regards the suburban business to the same general influences, together with the competition of the "Alley" elevated line and the growth of local electric lines in outlying districts. It will be noticed that during last year the rate of increase in population and suburban business has again taken an upward turn.

DISCUSSION.

Mr. Clarke.

T. C. Clarke, Past-President Am. Soc. C. E.—The wide differences in the cost of the application of electric power, in the opinion of experts, varying from $375 000 to $1 200 000, and of its operation, varying from $232 to $616 per day, shows how little was definitely known about the matter five years ago. The decision of the Illinois Central Railway Company to make no change from steam locomotives would have been justified for that reason alone, but the author has pointed out a much better reason, that the greater part of the Exposition business consisted of carrying large numbers of people from one terminal to another. This indicated long trains of cars at greater distances apart, say twelve cars carrying 1 000 passengers. There is no question that the steam locomotive is the most economical means of doing this class of business. When he comes to consider the question of the application of electricity to suburban traffic, he states the whole case very clearly and correctly. "Electricity is more desirable and economical for handling a large number of small transportation units at frequent intervals over short distances, while steam power" (meaning steam locomotive power) "is more desirable and economical for handling large units of transportation at high speeds, infrequent intervals, and over long distances." He should have added that the electric system is better adapted to frequent stops, and the steam locomotive to stops far apart.

The author, under the head of "minor problems," speaks of "the size of transportation units and whether independent motors of large power shall be used to haul long trains of trailers, or whether small transportation units, run at more frequent intervals, shall be adopted," with motors on the cars. In designing the rolling stock and structure of elevated electric railways in cities, this is the main point, and not one of minor consideration. Neglect to study this and to come to the correct conclusion has led to the financial failure of one of the largest electric elevated railways that has been constructed, and will lead to the financial failure of all others that follow the same lines.

Carrying passengers in a city does not differ from any other business. The first requisite is to get abundant traffic; the second, to handle it with economy. The Manhattan Railway is an instance of the first; the Brooklyn Elevated of the second.

Elevated lines run in competition with surface lines, and charge the same fare. The surface lines can beat them in all points but one. They afford more frequent stops; there is no climbing of stairs; cost of construction and, consequently, interest is less, and the system of transfers to branch lines is a great accommodation to the public. The elevated trains, not being impeded by surface traffic, can make better

Mr. Clarke. time; but for that, no person would ride in them, except to escape crowding.

Common sense would indicate that the managers of elevated lines should try to approach, so far as possible, the conditions which have made surface lines a success.

Frequent stops can only be attained, without losing too much time, by having a great power of acceleration. Any amount of power can be sent from the central reservoir, but if the wheels of the cars slip, a limit is reached. Therefore, instead of having only one-third of the weight of the train available for adhesion, as is the case where an electric locomotive draws a train of trailers, utilize the whole weight of the train and passengers by putting motors on every car, connected electrically and mechanically, and worked by a motorman at one end of the train. Another advantage resulting from this is that gradients can be steepened and the height of the stations and their stairways reduced.

If, in addition to this, short trains of light cars are used, the weight and cost of the structure can be greatly reduced, and the interest charges also. Small trains mean frequent trains to enable the traffic to be carried, and everybody knows there is no means of attracting traffic so powerful as that of frequent trains, as there is then no waiting at stations, which everybody hates.

The summing up of the whole matter is, that to make a city elevated railway a success, the surface electric system must be copied, and placed above obstructions from other traffic, and not the steam locomotive system of long trains at greater intervals.

Some persons say that this last method is a much more economical one of carrying traffic. Even if this were true, it would not be a strong argument, if there were but little traffic to carry. The statement does not seem to be borne out entirely by the facts. The cost of carrying passengers on the Brooklyn elevated steam railway for 1896 was 10.6 cents per car-mile run, and the number of passengers carried per car-mile run was 3.66. The Brooklyn surface trolley lines carried during same year 4.76 passengers per car-mile run, and at a cost per car-mile of 12.10 cents. The cost of carrying passengers on the Manhattan elevated lines in 1896 was 12.2 per car-mile run, and the number was 6 per car-mile run. The cost of carrying passengers on the Third Avenue line during same year was 11.94 cents per car-mile run, and the number was 5 per car-mile run.

All surface trolley lines would prefer, if conditions allowed it, to be able to run one motor car with one or two trailers. If they were placed on elevated structures of light construction, they could do this, and if motors were attached to all the cars, they could run more or less of them to suit the variations of traffic, and in case of a breakdown of the motors on one car there would always be a motor car at hand to take it away.

The process of evolution which develops everything along the fittest lines will make the city elevated railway of the future one of light structure, carrying light and very frequent trains, with motors on the cars themselves—a development of street trolley lines, and not of steam locomotive railroads. Mr. Clarke.

HENRY G. PROUT, M. Am. Soc. C. E.—It is improbable in the light of present knowledge of the subject that the traffic now handled by steam traction, if carried in the same manner and at the same intervals, could be handled cheaper by electricity. It would not be surprising if this statement were found to hold true of the Manhattan Elevated Railroad in New York, which is admirably adapted for economical electric working because the traffic is such that the central power stations could be operated under a condition of fairly uniform loading. Nevertheless the traffic on this road is handled under conditions giving great economy in steam traction; that is to say, the units are large, and could not be reduced even were electricity substituted for steam. It would be unsafe to run the trains at more frequent intervals then they are run now. Consequently to handle the same traffic, it is necessary to operate trains as heavy as those now in service, and it is possible that a thorough analysis of the problem would show that they could be handled more cheaply by steam than electricity. In 1895 the then general manager of the company stated that no one had been able to convince him of an economy in handling the traffic of the Manhattan Elevated Railroad by electricity which would pay the interest on the cost of the change. The present general manager, however, has the contrary opinion. Mr. Prout.

If the traffic can be massed in such a way as to be handled in large units it is probable that steam will handle it more cheaply than electricity for a long time to come, so far as can be foreseen now. It may be assumed, for instance, that the traffic can be hauled by a locomotive capable of developing 1 000 H.-P., and costing, say, for simplicity, $10 000. A central station of 1 000 H.-P., with the means of transmitting the power to the motor, will cost $80 000, taking about the mean of the author's figures, which range from $65 to $100 per horse-power. The interest on the difference in cost of a 1 000 H.-P. central station system and a locomotive of equal capacity would be more than the saving in the cost of coal effected by the use of electricity; moreover, it is questionable if there would be any appreciable saving in coal consumption. To generate and deliver a horse-power at the driving wheel of an electric car will probably require as much coal to be burned in the central station as in the locomotive, but it is true that cheaper coal may often be used in a central station than on a locomotive.

It is thus evident that the problem is more commercial than engineering. In order to secure traffic of the class discussed by the

Mr. Prout. author, it must be handled in small and frequently operated units. Owing to the competition of trolley roads, the question of the possible maximum economy is over-shadowed by the more important problem of securing and holding the traffic, even by more expensive methods of handling than those of the present time. Under the present systems of headway and speed, the business now done can be carried on more cheaply by steam than electricity, but the problem confronting the railroads is that the present business cannot be retained by such a service, which points to the application of electricity for certain limited uses.

Mr. Emery. CHARLES E. EMERY, M. Am. Soc. C. E.—The detailed information in the paper is more valuable from a historical standpoint than otherwise, because the development of electric traction in the last five years has been great. While the paper contains what may be termed predictions of possibilities by those who had investigated the subject thoroughly and have since proved they were right, it also contains considerable data from those who merely had ideas on the subject and had not proved them, which accounts for the variations in the estimates submitted.

The general principles underlying the introduction of electric traction are now pretty well understood. Where the traffic is handled by frequent, short trains, electricity has the advantage, while with heavy, long trains the advantage lies with the steam locomotive. So far as economy alone is concerned, it is probable that the steam locomotive nearly holds its own in a comparison with trolley practice, but there are other aspects of the problem to be considered.

In an approximate investigation of the cost of applying electricity to the Pennsylvania Railroad, 1 800 miles long, the speaker assumed the present movement of trains as a basis and estimated the cost of electric apparatus at the lowest figure yet discussed, or at about the same cost per pound as other classes of machinery. The cost of operation was also taken as low as seemed possible in practice. On this basis it was found that to run all trains on the road electrically instead of by steam would necessitate increasing the present gross receipts about one-tenth to pay the same dividends as at present. It follows that to make the substitution of electricity for steam profitable the traffic must be increased, as has been the history in changing horse to trolley lines.

An analysis of the cost of operating steam and electric roads is interesting. In the case of electricity, the loss from the power station to the rails is about 50% in round numbers. With an improved steam plant in the station the saving in fuel per horse-power delivered at the track would be about one-third of that required by the locomotive.

The probable difference in price of fuel would increase the saving to one-half. The saving in weight, due to the absence of the tender,

applied to the relative amount of coal used for different classes of engines, would increase the average saving in fuel to about 53 per cent. When it is considered, however, that the cost of fuel on railroads is only about one-tenth the total operating expenses, the saving would only be 5.3% of the operating expenses, which would be increased to about 6% when the saving in water is considered. The saving in fuel does not therefore affect the problem to a very important extent. In the case of a standard steam road there are many reasons why it is desirable to use an independent electric locomotive. In such a case the same number of trainmen would be required as for a steam locomotive and no reduction in their wages can be predicted. The use of electricity would make a slight reduction in the force of cleaners in the round-houses, but add the wages and other operating expenses of the large stations where the current is generated. Mr. Emery.

The use of electricity will also entail additional interest charges due to the cost of the generating station and its equipment and the overhead or third rail system of transmitting power from the station to the trains; and in equipping an old railroad already supplied with locomotives, the capital account will also be increased by the cost of the electric locomotives.

It is evident that the electric operation of a standard steam railroad makes it necessary in order to earn the same amount for dividends as at present, to increase the gross earnings sufficiently to meet the additional fixed and labor charges, less the comparatively small saving in fuel.

In the case of suburban steam traffic the reasoning is the same, except that at moderate speeds the motors can be put under the baggage car and driven by a single man, with the baggageman acting as a reserve in case of sickness or accident to the driver, so there would be a slight saving in the cost of labor. It is a curious fact, however, that the cost of operating the better class of railroads is about the same, whether they use trolleys, cables or steam locomotives, and is independent of the size of cars. It is merely an accident, due to the fact that the force required to pull a train on a standard steam road is less than that necessary on the dirt-covered trolley roads, the difference being due to the condition of the track. This cost of operation runs from 5 to 15 cents per car-mile, although there are few examples at either limit. The cost usually ranges from 10 to 12 cents per car-mile. The chief reason for the high cost in the case of trolley roads is due to the item of labor, the most noticeable example being afforded by the West End Railway in Boston. The use of the trolley in this case did not enable any improvement to be made in the average speed of the cars on account of congested streets, more capital had been invested, and more men employed to handle the increased traffic, so there was no reduction in the cost of operation per car-mile. Un-

Mr. Emery. doubtedly when the subway in Boston is finished, the cars will average a higher speed and more car-miles will be obtained than at present for the same or a less total expenditure.

Why has the trolley been successful? Partly because the power has been furnished more cheaply and conveniently than by horses, but chiefly because it enables the public to be served better. The cars stop where desired, make fair speeds, and avoid the climbing or descending of stairs incident to travel on an elevated railway. It is perfection for city traction and approaches it for suburban traffic, but for reasons given it is safe to predict that further electric developments will, for the present, be on suburban lines and not on steam operated roads.

Mr. Bates. C. J. Bates, M. Am. Soc. C. E.—The fundamental point in this discussion is whether or not any system of electric traction has been devised which will meet the exigencies of standard railroad operation. When this matter is settled, it will be time to discuss economies and details. No such system has yet been devised, and the trolley system for anything like trunk-line traffic may be said to be totally worthless. If any engineer will take the trouble to sketch out a yard where there is a complicated system of tracks, and endeavor to locate his pole and overhead wires where they cannot be reached by the rolling stock moving about the yard, he will see that the trolley system cannot be used.

In the important matter of taking up current from the conductors to operate the motors, but little improvement has been made since the author made the investigation on which the paper is based. It is reported that the third rail on the Nantasket road is to be divided into separate insulated sections. This, however, adds another difficulty, sparking, for the electric locomotive to overcome in moving from one section to another. This might be obviated by putting a motor on each car and arranging a method by which every car would take current from the third rail.

Mr. Hutchinson Cary T. Hutchinson, Assoc. M. Am. Soc. C. E.—The most sanguine electrical engineers have never seen quite such a rosy prospect for electric traction as Mr. Emery has presented in his statement that 10% increase in the gross receipts of the Pennsylvania Railroad would make electrical operation perfectly feasible. All electrical engineers have taken the position that there can be no substitution of electricity for steam on trunk railroads. The only condition under which electricity can be used successfully is where the load is strongly concentrated, when there are many units running under a short headway.

Enough stress has not been laid in the paper on the fact that the answers to the author's questions were made six years ago. At that time the parties asking the questions were groping in the dark, as everybody now knows. It has also not been clearly brought out that

all the questions were not clear-cut, and the conditions were not fully defined. This accounts for much of the confusion between the replies. Another cause was the difference in opinion as to the meaning of terms. In answering Question 40, for example, a speed of 100 revolutions per minute is variously stated as high, medium and low. Apart from this matter, however, it may be said that two or three of the companies could have installed the desired plant successfully. In the Baltimore and Ohio tunnel work, the conditions were more onerous and differed more from trolley practice than anything attempted at Chicago, but the undertaking was carried out with entire success by one of the companies tendering for the Illinois Central contract. Mr. Hutchinson

The subject of elevated railroad operation has been presented in a manner not quite fair to electricity, in the statement that there could be no saving in operating expenses, because the trains would probably have to be of the same size in order to accommodate the traffic. The conditions could be met by changing the size of the units as the traffic changes, employing independent driving for each motor, and increasing the carrying capacity as the traffic increases. This plan has been proposed, and there seems to be no reason why it should not be carried out, except the difficulty of controlling the motors of a number of individual cars. The locomotive does not fit the work at all, and separately driven motor cars will be used in all probability. Another objection which has been raised to the use of electricity in yards is the complication of poles and overhead wiring, but no one would attempt to use the overhead trolley under such conditions. Some surface method, such as a divided third rail, would be adopted.

W. H. Knight, M. Am. Soc. C. E.—The electric motor is handicapped to a certain extent as compared with reciprocating motors by the pulsations of its power. Unless an elaborate rheostatic means of controlling the current is used, the power is bound to be applied in more or less uneven steps, quite as uneven as the variations in horizontal effect due to the angularity of the connecting rods of a steam locomotive. Mr. Knight.

At the time the company with which the speaker was then connected submitted its estimates to the author for the work mentioned in the paper, it was also discussing two more untried problems in electric traction, the Intramural Railway of the Columbian Exposition and the 100-ton locomotive for the Baltimore and Ohio tunnel. Both these problems it solved successfully, although there were a few disappointments, and some of the things prophesied would not come about. At that time estimates were sometimes made by people who had absolutely no experience with the subject, which naturally threw suspicion on every one.

In regard to the elevated railroad problem, which is more directly interesting to electricians than steam traffic generally, because of the

Mr. Knight. possibility of avoiding trolley wires, the direction in which progress lies is apparently in the line of longer trains moving more rapidly. The whole object of the elevated railroad is speed, and speed cannot be had with short headways. If it were merely a matter of carrying the greatest number of people, a comparatively slow speed and short headway would solve it. On the New York and Brooklyn Bridge a speed of 6 miles an hour will carry the greatest number of people. A speed of 15 or 16 miles could be attained, but the motive power expense would have to be doubled, which is inadmissible. Electricity is now able to handle trains of five to ten cars at a speed of 13 miles per hour without increasing the weight of the elevated structure over what it is at present. The steam locomotive can make only 11 to 12 miles an hour, because it would otherwise have to carry too great a load on the drivers for the safety of the structure, and because it cannot be moved quickly at the terminals. The electric motor, being an integral part of the train, does away with the need of shifting engines. If the Manhattan Elevated Railroad Company ever solves the problem of earning larger dividends, it will probably be by running longer trains at greater speeds, and not by dividing the trains into smaller units run on shorter headways. To do this it would, of course, be necessary to improve the facilities for loading and unloading the cars. It would make little difference, so far as speed is concerned, whether the cars were all equipped with motors, or all the electric apparatus concentrated on one car. The company with which the speaker was formerly connected advocated concentrating the apparatus, for the reason that one car gives sufficient weight, distributed over eight wheels, to afford all the traction needed.

CORRESPONDENCE.

EDWARD BARRINGTON, Esq.—There is hardly any doubt as to the practicability of substituting electricity for steam as a motive power for suburban traffic. The economical aspect of the question can be figured closely by those familiar with the subject, as they have had ten years' experience on the street railways, together with that of the several steam roads now using electricity, on which to base their calculations. Mr. Barrington.

Motor cars having a capacity of 100 H.-P. each, but capable of developing up to 200 H.-P. for short periods, should be able to handle the present service of the Illinois Central Railway, and the power should be divided between two motors.

The answers to the author's queries seem to have developed quite a diversity of opinion and information. It would probably take 6 000 H.-P. to cover satisfactorily the suburban traffic of the Illinois Central, including the several branches, which would be divided into four units of 1 500 H.-P. each, and eight dynamos of 750 H.-P. each, with Babcock & Wilcox water-tube boilers, mechanical stokers, condensers, heaters, separators, and all accessory apparatus. The approximate cost of power station, plant, line, block-signal system, thirty-three combination motor cars, etc., should not exceed $750 000. This does not cover cost of site for power plant. There is no real necessity for any loss being incurred through inactivity of the present suburban equipment, as the locomotives can be used elsewhere, and the coaches will remain in active service. At $1 per ton for coal, the cost of operation, with careful management, should not exceed $25 per horse-power per annum. An electrical engineer, thoroughly conversant with mechanical engineering, would be quite essential.

Although the writer's estimates are based on the overhead system of transmission, he strongly advocates the third-rail system with low voltage. With ordinary precautions, no danger need be counted upon. The difference in cost between the third-rail system and the overhead system would not be material. With the latter the poles should be placed between the tracks, from 90 to 100 ft. apart, and the wires supported by the bracket suspension method. Trolley wires should be No. 00, B. & S. gauge, and feed wires No. 0000. With first-class construction, the cost of repairs would be merely nominal. Fifteen per cent. of extra equipment should provide for repairs and contingencies. The repair shop should be thoroughly equipped with the best tools, etc., and be under the supervision of the engineer in charge. The motor cars should be built on the vestibule plan, thus protecting the motorman from the inclemencies of the weather.

Many railway managers, and more especially those connected with eastern roads, have pretty much made up their minds that it is not merely a theory that confronts them, and that if they wish to hold

Mr. Barrington. their patronage and pay dividends they must fight electricity with electricity. Although electricity will undoubtedly supersede steam in the not-distant future, there does not appear to be the slightest reason for uneasiness on the part of any existing interest, as such changes will take place in conformity with well-defined laws of progress, which must infallibly operate to compensate adequately for all apparent losses incurred during the period of transformation, and will have their analogy, so far as economic consequences to existing interests are concerned, in the change from the horse-car or stage coach to the electric motor car or steam locomotive.

It has been carefully estimated that the adoption of electricity in place of steam on trunk lines would effect a saving of from 10 to 15% of their operating expenses annually. Included in this are the repairs, fuel, water and other supplies for locomotives, and wages of firemen. All items in which there may be a reasonable doubt are eliminated, and the steam power given the benefit of the doubt. It is problematical whether any saving could be effected in conducting transportation, wages of trainmen, repairs of roadbed, renewal of ties, repairs of bridges, repairs of shop machinery or wages of engineers.

In estimating the initial cost of installing a railroad with an electrical equipment, several methods are employed to determine the amount of power needed, as follows:

Take the number of miles run per year by all trains and reduce to an hourly traffic and multiply by the power required per train.

Take the yearly movement of freight and passengers, and reduce it to an hourly basis, with proper allowances.

Take the number of locomotives and multiply by the average power developed by each, making proper allowances for engines not in use.

Take the coal consumption and assume a certain consumption per horse-power-hour.

Of course each of these reductions should arrive at the same conclusions, nearly.

The last estimate is probably the most accurate, and 25% is added to allow for increased traffic at certain seasons of the year, and 25% again to cover the heaviest demands during the day at such times. This gives the grand total required. It is necessary, therefore, to figure on about 2.4 times the amount of power required on an average.

The power stations should have a capacity of about 6 500 H.-P., and this should be sufficient, generally speaking, for a 45-mile section of road. The equipping of each station will cost about $625 000. Motors will cost about $6 000 each. The net annual saving in operating expenses is figured at 11% on the total cost of installation.

There is not a line of railway in the United States more favorably situated to introduce electric traction than the Illinois Central, and

the power station could be advantageously located at either Grand Crossing or Burnside Crossing, whichever presents the best facilities for furnishing good water for condensing purposes. Burnside Crossing is peculiarly well adapted for a power plant for many reasons. Mr. Barrington.

Most electric railways pay too much for their power. Some develop it cheaply and waste it on the line; others develop it at high cost, while they distribute it and utilize it economically, while others again may be losing at only the motor end of the line. When the steam locomotive is discarded, the most economical and convenient method will be to put the motor under a baggage or combination car, weight being unnecessary, because of the fact that the even pull at a tangent to the circumference of the motor armature produces an apparently greater possible traction effort per ton of weight than is the case with a reciprocating motor, and in addition reduces the tendency of the wheels to slip at starting. This feature of the electric motor is the one above all others which establishes the fact that it has come to stay, no matter what development may be made in air, gas or other motors which have to convert a reciprocating into a rotating motion; and the fact that an electric motor supplied directly from a central station has a practically unlimited supply to draw from puts it far ahead of any motor which carries its supply upon its back, whether it be in air-tanks, storage batteries, oil reservoirs or coal and water bunkers. Where the motor cars are equipped with double motors and two controllers, there is no one thing can happen to prevent the motorman from getting his car or train to its terminus. The speed may be decreased, but the train can be moved. Of course, this presupposes a feeder system practically impossible to interrupt, which will come with the advent of electricity on steam roads.

Experience with power plants shows that the transmission of electric energy a distance of 50 miles with a pressure of 20 000 volts is practicable; beyond this limit the transmission would be more or less experimental. Commercial transmissions are in successful operation for distances of 35 miles, and as high as 15 000 volts. The best plan for the long-distance transmission of energy for general purposes is the three-phase alternating system. Where batteries are used, it is best to place them at the end of feeder wires to obtain the advantage of a constant load on the wire. When the economical area of direct distribution is passed, boosters should be employed directly or in connection with batteries, to a distance of 10 or 12 miles from the station, and beyond this, rotary transformers, with or without batteries, should be used. Where the power is generated in or near the area of distribution, it is best to use one station situated at the most economical point for producing power. Local conditions, of course, largely influence such matters.

Mr. Barrington. Relative to electric distribution, the booster system would probably be the most advantageous on the author's lines, owing to the variable nature of the traffic, both during the day and for different seasons. If any transforming device is employed to feed a distant section of the lines, it must be remembered that the capacity of the device must be great enough to care for the maximum demand on this section. Should it be necessary to feed some line where the load has considerable momentary fluctuation, but where the traffic is moderately constant during the year, the booster could be used with a storage battery at the end of its feeder, the battery supplying the line. The advantages of this combination are greater than with the simple booster, and in many cases they will compensate for the interest and depreciation on the battery and the loss in it. If the arrangement is properly made, the load on the booster and line wire will be practically constant, thus decreasing the capacity of the booster to that required for the average load, while less copper will be required for a given loss. The battery should be located near the points of consumption and not in the station. By this system, a booster with storage batteries, it is possible, assuming the same loss, to transmit power to a distance of 10 miles with approximately the same amount of copper that would be required for a 5-mile transmission on the direct system. It increases the economical radius of distribution twice, and the area of distribution four times. There is little possibility of the complete shutdown of such a station with a proper reserve, a careful system of duplex steam piping, and with fire-proof construction of the station. Storage batteries would look out for any momentary interruptions on the feeders.

The selection of the site of the power house is a very important factor in the economical operation of the road. Striking advances are noted in the plans under which they are now constructed compared with those of some years ago. The distribution of room is more sightly and economical. The false economy of building only for present needs has been observed.

Determine carefully the required capacity of the engines, generators and boilers, and be governed accordingly in the erection of the plant. Closely estimate the amount of generating capacity required, taking always into account the grades and curves, nature of holiday service, frequency of stops and other governing considerations. Having settled upon the capacity of the generators, proceed to determine the capacity of the connected engine, but bear in mind that an engine has not the capacity for excessive overload that a generator has, and that an engine is not called upon to perform more than 20% or 25% above its rating, even for a short time. With regard to the boiler power, it is obvious that it has only to deal with the average of the total load.

As prime movers gas and oil motors are now receiving much consideration, and there is doubtless a great future before them, the working cost per kilowatt being much reduced. Mr. Barrington.

Direct or indirect driving seems to be an unsettled question. For steam-driven plants, direct driving is an undoubted advantage, although it must be borne in mind that a fly-wheel suitable for electric-light dynamos will not be large enough for traction purposes, since in the latter the load fluctuates very rapidly between zero and the maximum. Heavy fly-wheels are very essential. The direct-coupled plant will cost slightly more than the direct-belted with independent engines, but much less than any plant based on large engines, with the attendant mass of counter shafting, clutch pulleys, belts, belt-tighteners, etc. Add to this, the real estate and building item, and the chances are in favor of reducing the original investment one-half in an ordinary plant. The relation of this fact to dividends is apparent.

Frequently the cost of operating power stations is figured from the basis of car-miles. This is liable to be deceptive, as insufficient copper, poor bonding and defective car equipments will make a bad showing for any station. The correct method is to note the output at the bus-bar, and figure upon the basis of electrical horse-power.

The study of the details of such a plant as would be required to operate the Illinois Central suburban service, including express trains and the branch lines to Blue Island, Homewood and South Chicago, is a most interesting one. Taking into consideration the large sum invested in coaches, $567 000, it would probably be judicious for this company to introduce motors of large power, capable of hauling the trains now used and under the same intervals of time. The steam locomotives could be used on other work of this system, and would not be a dead loss. The chief expense of installation would be the power plant, system of transmission and 33 combination baggage and motor cars, the total cost being not far from double that of the least estimate made by the electrical companies in 1891.

There is little difficulty in deciding the most economical methods of transmission for any locality after the ground has been gone over, the nature and amount of the service determined, and the cost to produce power at the central station figured. Where a great number of trains are run at frequent intervals, as on the Illinois Central, the conditions are especially favorable for the adoption of electricity. Almost perfect dynamos can be now furnished with an efficiency of 98 or 99 per cent. Very efficient slow-speed stationary engines can be had, and equally efficient electric motors. The chief problem is that of getting the current into the moving train. The objection to the overhead trolley is its unsightliness and obstructing the view of signals, and the third rail may be dangerous, although if a low voltage is used and only ordinary precautions taken, no danger need be anticipated.

Mr. Barrington

The advantages of electric traction for accommodation trains over comparatively short distances for suburban service around large cities, and to a certain extent for the transportation of freight, are very marked. A quick start, freedom from smoke and cinders, the slight expense of additional motor cars for extra equipment, all recommend it very highly.

Electric motor repairs cost infinitely less than those of steam locomotives, because the mechanism is far more simple. There are fewer moving parts, and these are not so much exposed to the action of mud, sand and water. More miles are run per day, or more hours of service are obtained per day, with electric motors than with steam locomotives, so that the cost of labor per mile is less with the former, and the amount of work done with a given sum invested is larger. When electric motors of large size and higher speed than those now used are made to take the place of locomotives, they will run about the same number of hours as the motors now in use, but will cover continuously from two and a half to three times the distance now covered by the locomotives. Locomotives must be run into the roundhouse and thoroughly examined and cleaned up more frequently. The electric motors used to move a train can be placed under one of the cars, so that the weight of the train is reduced and less power is required for moving it.

Operating figures secured from a number of large modern power houses recently range from $0.0075 to $0.0125 per kilowatt hour; these figures include the cost of coal, water, supplies, repairs and labor, but do not include taxes, insurance, interest or depreciation. Converting these figures into annual cost, it will be seen that they are equivalent, on the basis of twenty-hour service per day, to from $54 75 to $91 25 per kilowatt per annum, or from $41 to $68 per electrical horse-power per annum. Charles E. Emery, M. Am. Soc. C. E., in a discussion of the cost of producing power in 500 H.-P. units, made in 1893, showed that it could be delivered on the dynamo shaft of a direct-connected engine for $30 39 per horse-power per annum, with $2 coal; $38 45, with $3 coal; and $46 51, with $4 coal. Assuming a dynamo efficiency of 93%, these figures would become $32 70, $41 30 and $50 respectively, all based on a twenty-hour day for 365 days, and covering fuel, supplies, labor and repairs on engines alone. It seems, therefore, that there is an opportunity for electric railway plants to increase their economy, particularly in view of the fact that units larger than 500 H.-P. are usually found in most modern stations, and at least the labor account ought to be less than in Mr. Emery's assumed examples. To be sure, most stations work under disadvantages, such as inability to obtain condensing water, heavy cost of fuel, and enormous fluctuations in load, which prevent maximum engine economy from being reached.

There are some features of the single-acting compound engine

which it might be well to dwell upon, such as uniform economy over wide ranges of load, instantaneous regulation by inertia, limited space required, low cost of foundation, ease of attendance, ability to stand hard service under long-continued runs, and particularly low cost of maintenance and repairs, the latter being only 1.6% per annum of the cost. In the case of the Illinois Central installation, triple expansion engines of either 1 500 or 1 000 H.-P. each would probably be used. Mr. Barrington.

Cleanliness in and about the power station will pay higher dividends than anything else connected with it, as misplaced tools and innumerable other articles will not have to be paid for, and the employees will take more interest where things are kept scrupulously clean and neat. In stations of over 2 000 H.-P. it will pay to extract the oil from old wipers. It is done by enclosing them in a tank into which a steam jet has been inserted. The oil on rising to the top can be drawn off for purification, the wipers dried out and used again, repeating the operation until they are worn out.

Iron or steel chimneys are advised, as they are cheaper and their factor of safety is ten, while that of brick chimneys is scarcely two.

Experience has proved that the total cost of repairs for rolling stock per car-mile averages about $0.017, divided as follows: Trucks, $0.002; motors, $0.005; bodies, $0.010. These figures include both labor and material, the latter costing about one-tenth more than the former. Repainting covers about 20% of the cost of repairs. By economies made in the car repair shop, such as carrying on all work on the piece system, these figures can be materially lowered. Results so far secured indicate a reduction of about 20 per cent.

It would be very interesting to know exactly what effect the electric and cable roads have had on the suburban receipts of the Illinois Central Railway during the last four years. Most steam roads have completely ignored this character of competition; in other cases it has been met by reduced rates and improved service, or the train service has been reduced and retrenchments made in other directions. In many localities, the increased inducements to travel afforded by the opening of rapid transit lines, and the improved facilities given by the old roads, have materially increased the traffic, so that it may be a question whether the net result has been altogether loss. The Illinois Central has refused to come down to a 5-cent fare, although the Northern Pacific gives a 20-mile ride for that amount. It is, undoubtedly, a fact, however, that the rapid transit surface roads are not only catching the short-haul passengers, but also many riding for long distances who find the surface roads more convenient for their purposes and now fast enough to use.

Charles Henry Davis, M. Am. Soc. C. E.—The paper is mostly of interest as history in the development of electric traction, showing clearly the truth of the author's words: "Engineers giving this matter Mr. Davis.

Mr. Davis. their attention have been enthusiastic electricians; they have seldom been practical or expert mechanics," and, the writer would add, usually inexperienced as railroad engineers. In the growth of the electrical industry its greatest weakness has been displayed in mechanical design. The paper will be received with pleasure by those in the electrical business as another indication of the probable introduction of electric traction on parts of some of the larger steam railway lines. The use of electricity for suburban work on some steam railway systems is certain to come within a few years, but it will be adopted by conservative managers only when it can be shown to produce larger net receipts than steam locomotives. Higher operating expenses if accompanied with larger gross receipts might produce greater net results. One of the difficulties in the way is the necessity of discarding certain parts of the old system upon the cost of which interest must be paid, but this will be partly overcome by their use on other parts of the line which continue to be operated by steam locomotives. The writer will make some notes on the paper which are intended to bring out the unreliable nature of many of the answers, and the underlying causes affecting them, together with the many discrepancies and the wide divergence of opinions.

The author opens his paper by disclaiming any expert electrical knowledge, thereby inferring that such knowledge is requisite for a proper solution of the problem in hand. While the expert electrical engineer is a necessity for the best design and execution of part of such a change from steam locomotives to electricity, yet the engineering problems involved are much more those which can be best solved by sound mechanical and civil engineering as applied to transportation lines.

The method adopted by the author in studying the problem shows a clear judgment, and, it is hoped, will be repeated in his present investigations. Most of the questions are calculated to draw out desirable information, although many more could have been asked to advantage. The statement of conditions made to the electric companies is clear and concise, and sufficiently full for a preliminary study, and seems to have been understood by all, except as to whether 20 miles was the average or the maximum speed per hour. It was, undoubtedly, the former, although not so expressed by the use of the word "average."

The questions and answers will be discussed in detail and in consecutive order. The figures given are not always exact, but they will be found to be approximately correct and sufficiently so for the purposes of this discussion. The writer does not wish to be understood as attempting to belittle the labor and skill of those engineers connected with the large electric companies (many of whom are among the leaders in their profession), who have done so much for the permanent advance-

ment of the electrical industry, but wishes to give some idea of the methods, affiliations and other causes in the business which resulted in such widely divergent, inconsistent and inaccurate answers. Mr. Davis.

Question 1.—What capacity should motors have in horse-power?

Although the conditions of speed, load and character of track were given, the answers vary 100% from 100 H.-P. minimum to 200 H.-P. maximum, as follows:

(*a*)	150	H.-P.	divided into	2	motors.
(*b*)	150–200	"	"	2	"
(*c*)	100	"	"	2	"
(*d*)	100	"	"	2	or 4 motors.
(*e*)	200	"	"	2	"

Undoubtedly one cause of the large variation in expressed horse-power is due to the fact that neither the question nor answers define what is meant by horse-power. It is quite possible that 150 H.-P. of one was only equivalent in capacity to 100 H.-P. of another. It is as necessary in determining the horse-power capacity of a motor to define its ampere current at a given electromotive force within a given heat limit, etc., as it is to define the steam pressure and speed, etc., of a steam engine before the horse-power can be intelligently determined. *d* undoubtedly advocated four motors, to increase the tractive effect, and because it was not until the latter part of 1892 that railway motors of over 30 H.-P. were in constant and successful operation for service of this character. It would therefore seem that each company was advocating the use of apparatus which was experimental. It is unnecessary here to go into the mathematics that would have accurately determined the necessary horse-power. *c* gave the lowest estimate of motor horse-power, a tendency it invariably had, and which, together with the lightness of its mechanical work, was a large element in the subsequent failure of the types designed by it. Although *d* made the same estimate of motor horse-power, at that time it underrated its apparatus, and the greater subdivision, recommended by this company, would have given a greater percentage of surplus power to call upon, if loads and speeds required it.

Question 2.—What will these motors cost? In giving cost, separate the cost of motors and motor cars.

Omitting the cost of bodies, which would largely depend upon their style and finish, and noting that *a* estimates on an electric locomotive and recommends its use, while the others advocate motor cars carrying passengers, it is found:

a	estimates	$8 000 for motors and trucks for locomotive.
b	"	7 000 for motor car without body (writer has deducted $1 000 for body, which assumes that trucks were estimated to cost $6 000; both figures and their sum obviously wide of the mark).

Mr. Davis.

c estimates $6 000 for motor car without the body and air brakes.

d " 5 000 for motor car complete without bodies.

e No estimate given.

The variation is from $5 000 to $8 000, or 60%; *a* does not state whether cab is included, while all but *c* are indefinite about brakes; this inexactness and the varying capacity in horse-power, together with the fact that, in most cases, new motors would have been built, caused the large difference in estimated costs.

Question 3.—Give approximate cost of trailers. Cars to be open cars, with cross seats, on first-class double trucks.

The answers are of no particular interest, as the cost, outside of electric light wiring and braking appliances, is dependent upon style, finish and local requirements, and entirely independent of the use of electric traction. Had the system contemplated been one where every car was a motor car, then the cost of electric connections, when running trains of two or more motor cars, would have needed careful consideration.

Question 4.—Is it desirable to have horse-power used for motor cars consolidated in one unit or divided into two?

The companies are unanimous in advocating a division of motor horse-power; all but *d* advise two units, it inclines toward four motors (see Question 1). *e* thinks that running two motors in series, enabling the use of 1 000 volts on the line, would be of advantage in saving three-fourths the weight of copper as compared with 500 volts. It would be interesting to know how this company proposed to operate and control the motors, and whether they had ever done it at this potential.

Question 5.—What is the best method to transmit the power of the motor to the axle, by gear or by crank?

a recommends gearless or geared motors.

b " gearless motors.

c " crank and parallel-rod connections.

d " single-reduction geared motors.

e " geared motors.

In the light of history it is interesting to study these recommendations and to speculate as to the causes influencing the statements of each company. The double-reduction geared motor had been used up to the first part of 1891, although the Wenstrom Company had advertised, and nominally placed upon the market, a single-reduction geared motor during the latter part of 1890. The S. R. G. motor of the Thomson-Houston Company was the first practical success in the single-reduction field, although the Wightman came out about the same time, as well as the Edison, and a little later the Westinghouse.

Mr. Davis.

About April, 1891, the Short and Westinghouse companies advertised the gearless motor, and in the fall of that year the writer had the opportunity, at Pittsburg, of testing a car equipped with Short gearless motors. The cost of building the gearless motor and the large current used by it when starting or running below speed were causes which lead to its abandonment, but recent developments and improvements point to its possible future use in certain fields of traction work. In 1889 the Edison General Electric Company was formed out of various allied interests, and in 1890 this company purchased the stock of the Sprague Electric Railway and Motor Company. In the same year the Thomson-Houston Electric Company purchased a controlling interest in the Brush Electric Company, thereby securing a majority of the stock of the Short Electric Railway Company. The absorption of the Sprague Company by the Edison resulted in the cancellation of territorial rights of the former's agents. These agents sought the Westinghouse Company, and it was mostly through this circumstance that the latter company became, at that time, active in the street railway field. The Thomson-Houston Company proposed to furnish its W. P. (water-proof) motors, which were then the best in the market and the least experimental; the Short Company, really the Thomson-Houston Company, so far as its proposal to the Illinois Central Railroad was concerned, offered a gearless motor, a few of which had been on the market about six months, although they were of much smaller size than those necessary for the proposed work, and even then it was seen that they would not be a success. This company was used by the Thomson-Houston Company to double its chances in competition. The Westinghouse Company was suggesting either gearless or single-reduction motors so as to cover the field; its railway department was then suffering from lack of experience and engineering ability in this particular line, the department being mostly dependent upon the experience of sales-agents from the Sprague Company, although some special engineering talent had also gone to it; these agents, however, secured an enormous business for their new associates. The Edison Company, through consolidations, constant changes of management and internal friction, which resulted in its absorption by the Thomson-Houston Company in May, 1892, had so demoralized its railway motor work as to have little of value to offer its customers. Its single-reduction motor was not a success, and the use of cranks and parallel rods for connections between motors and axles, which it recommended because of its recently acquired control of the Eickemeyer-Field methods, was a failure. The weakness of *e* is apparent from the meager information imparted in most of its replies.

Question 6.—What parts of motors are liable to give the most trouble from breakages, and what is the best and quickest method of handling motors that are disabled out on the line, and to avoid the least delays to traffic ?

Mr. Davis. *a* thinks that there will be no trouble from breakage; gears cause the most trouble according to *b*, although the burning out of fields and armatures may do so also; armatures and commutators cause the most trouble according to *c;* bearings and gears in the opinion of *d;* and gears in the experience of *e*. To get a disabled car in from the line it is variously suggested to use the unaffected motor, duplicate trolley wire and trolleys, and to push the stalled train by the next succeeding either to a siding of terminal; while *c* would, under some circumstances, quickly remove the connecting rods, presumably with the ease of steam locomotive practice "for the past 40 years." The answers indicate the general condition of the motors of each company. The Westinghouse Company, from lack of experience, did not know what parts caused the most trouble, therefore stated there would be none. The Short Company favored gearless motors, and therefore thought that gears would most frequently break. The Edison Company had, at that time, been troubled with burn-outs due to lightness of construction, high ratings and an attempt towards too great electrical efficiency at the sacrifice of repair account, resulting in great casualties to armatures and commutators where its motors were used, and therefore stated that these gave the most trouble. The Thomson-Houston Company had the greatest trouble with bearings and gears, for in its mechanical work it was weak as compared with its electrical work, the reverse being true with the Westinghouse Company at that time, and the Thomson-Houston Company therefore expressed its belief that these parts would need frequent renewals.

Question 7.—What is the best known brake for electric cars and motors suitable to the requirements of this line?

All the companies answered that the air brake operated by an electric motor on the motor car would give the best results; the writer cannot from memory state whether this had ever been done, but it certainly had not passed the experimental stage. The development to date is not what has been hoped for, there being room for future improvements.

Question 8.—What is the largest motor now manufactured, and where is it operated?

The answers show, as stated under Question 1, that 30 H.-P. was the largest railway motor then operated in passenger service, and that therefore each company proposed to furnish entirely new motors, except in the case of *d*, which proposed four motors of 25 H.-P.

Question 9.—In using two motors on a car it was understood that the motors work separately on both forward and rear trucks, and that the motor cars do not have to be turned at end of line.

Question 10.—Can both motors be used at once in the same direction, and can motors be reversed on line in an opposite direction, and can both motors be operated from same end of car?

Motor cars or electric locomotives were arranged at that time as now, so that motors could be run together or separately, reversed while running, operated together from either end of car, and the entire machine run in either direction ; the methods for accomplishing these results were very different and crude then as compared with those used to-day. Mr. Davis.

Question 11.—If the motor is designed for a speed of 20 miles an hour with a certain load, can the speed be increased with a less load without overstraining the motor and without any change in the mechanism, and what percentage can speed be increased?

All the companies answered in the affirmative ; up to this time motors had been controlled by means of rheostats, except in the earlier experiments of Mr. Frank J. Sprague, who had advocated and successfully used series-parallel controllers. It was about the winter of 1891–92 that the various companies began using series-parallel controller stands which have since been developed to their present efficient and flexible modes of handling the motor equipments, enabling the motors to be run efficiently and satisfactorily at various ranges of speed, without jerking at the starting or intermediate points of acceleration, and without undue heating at any stage. What has been done in the past is likely to be surpassed in the future.

Question 12.—In how short a distance can trains described above be brought to a stop with existing brakes from a speed of 20 miles per hour ?

Except as to the feasibility of operating the air pump of the Westinghouse air brake system by an electric motor and the easy and quick reversal of the motors, the length in feet through which these trains could be stopped depended upon conditions which were entirely similar to steam railway practice. This question has been the subject of many elaborate articles with interesting tests, and is a matter outside the objects of this paper.

Question 13.—Upon the line under consideration, what would be the best location for the power house, taking into consideration that after the World's Fair the line will be extended 7 miles south, and that trains will have to stop at suburban stations at intervals of $\frac{1}{2}$ mile.

All but *b* and *e* took the view that the station should be located at the middle of the line; *b* thought that within 2 or 3 miles of this point would be safe to work in, while *c* was the only one which advocated a location nearer the end from which the extension was to be made; *c* and *d* thought an additional station desirable, after the World's Fair was over, each dividing the line into three parts. The answers to this question show how little thought was given to the problem by most of the companies. For the most economical distribution of electrical energy, the power house should, of course, be

Mr. Davis. located at the center of gravity (so to speak) of the units to be moved. This may or may not be the middle of the line. It is determined by treating the trains as weights located as they would be at the time of the heaviest travel. This factor is rarely, if ever, the limiting one in locating a power house. The question of available estate, delivery of coal, proximity of water, future growth and the like, are usually of more importance, while the center of gravity is more or less widely departed from. As the business from the World's Fair was only for a few months, it would have been cheaper, in the long run, to locate the power station or stations, irrespective of this factor. This would have made it necessary to put up additional temporary feeder lines and take them down when no longer necessary, rather than in the future labor under the disadvantage of a station much too large, if located at the right point, when an additional station was erected for the extension; or the disadvantage of a station poorly located, although large enough, should it alone be used when the line was extended.

Question 14.—How much power plant would be required to operate from sixty to seventy trains of 65 to 70 tons each at a speed of 20 miles per hour?

Question 15.—What excess power will be required in such a plant, if any?

Question 16.—What would you recommend as to the proper units into which this power should be divided?

Question 17.—If the requirements for power should be reduced 50% after the World's Fair, what power of each unit would you recommend?

Answers were as follows:

	Horse-power, Question 14.	Excess horse-power.	Total horse-power.	Horse-Power of each unit.		Total horse-power of trains (70).	Difference in horse-power.
				Dynamo.	Engine.		
(*a*).....	4 800	8 000	12 800	800	800	10 500	+2 300
(*b*).....	8 000	2 000	10 000	500	1 000	10 500	— 500
(*c*).....	5 000	.....	5 000	400	400	7 000	—2 000
(*d*).....	4 000	1 000	5 000	500	500	7 000	—2 000
(*e*).....	12 500	2 500	15 000	750	1 500	14 000	+1 000

Why *a* should desire 166% additional capacity as spare machinery is hard to understand except on the score of ignorance or unreliable apparatus. It is also hard to see the advantage of two generators direct-connected to one engine as in the case of *b*: no one would think of one 1 000 H.-P. dynamo driven by two 500 H.-P. engines on the ground that "one engine (dynamo) might break down." *c*, as was its usual tendency, estimated on a low capacity with no surplus; *d* was below *c*, which was unusual with this company, as it too often installed apparatus entirely too large for economical work; this, however,

could be explained by its desire to make a low bid. The following vari- Mr. Davis.
ations between highest and lowest are interesting.

1. Horse-power, Question 14 ..... 212%
2. Excess horse-power 700%
3. Total horse-power 200%
4. Horse-power of each unit (dynamos) 100%
5. " " " (engines) 275%
6. Total horse-power of trains 100%
7. Difference in horse-power (total horse-power in station and total in trains) 215%

Such variations are astonishing when one realizes that even at that time the efficiency of boilers, engines, generators, line and motors was known with reasonable accuracy, even if parts of the system were uneconomical when compared with apparatus of to-day. There is no doubt that a large part of the variation was due to inaccuracy in the estimated horse-power required per train, and to the element of judgment in estimating the maximum station load and a desirable surplus.

Question 18.—How many square feet in space will be required for the erection of steam and electric power plant, including boiler house?

Question 19.—Give your opinion as to the most economical and best kind of boilers, engines and generators to use for such a plant.

Question 20.—Give approximate cost of power plant, to erect engines, boilers, generators, separately.

Question 38.—Do you recommend horizontal or upright engines?

Question 39.—What is the best form of connection between engines and generators, belts or countershaft?

Question 40.—Are high or low speeds preferable, and about how many revolutions per minute?

The following variations in area required depend upon the peculiar design of steam plant recommended by each company, such as whether generators were belted or direct-connected:

	Square Feet Ground.		Boilers.	Engines.	Generators.
	One story.	Two stories.			
(*a*)...	75 000	.....	B. & W.	Corliss, 300 revs.	Westinghouse.
(*b*)...	43 750	21 875	Water-tube.	Horizontal Corliss, 100 revs.	Direct-connected.
(*c*)...	15-25 000	12 000	" "	Horizontal compound, condensing medium speed, 100 revs.	" "
(*d*)...	25 375	.....	B. & W.	Compound or triple-expansion, 100 revs.	" "
(*e*)...	27 300	.....	Climax.	Vertical triple condensing Corliss, 100 revs.	" "

Mr. Davis. It will be seen that in each case the following space per horse-power has been allowed:

	Square Feet Ground.		Horse-power.	Square feet per horse-power.
	One story.	Two stories.		
(*a*).....	75 000	.....	12 800	5.85
(*b*).....	43 750	21 875	10 000	4.37
(*c*).....	15–25 000	12 000	5 000	3.00–5.00
(*d*).....	25 375	.....	5 000	5 07
(*e*).....	27 300	.....	15 000	1.80

a intended to use belted or rope-driven apparatus without shafting. *e* saved space by the use of vertical boilers and engines; unless ample boiler power were furnished so as not to force them when in use and good water were obtainable, the use of vertical boilers would have proved undesirable. The estimates of cost for power plant with building complete, but without real estate, are as follows:

	Cost.	Horse-power.	Per Horse-Power.			
			Steam plant.	Electric plant.	Building.	Total.
(*a*).....	$475 000	12 800	.....	.....	.....	$37
(*b*).....	1 000 000	10 000	$55 (?)	$35 (?)	$10 (?)	100
(*c*).....	320 000	5 000	40	24	.....	64*
(*d*).....	455 000	5 000	46	35	10	91
(*e*).....	1 169 000	15 000	.....	.....	.....	78

* Without building.

These total costs vary 216%, if $10 per horse-power is added as in other cases for buildings, not included in *c*'s estimate, and the variation is 170% in cost per horse-power, or 35% if the Westinghouse belted apparatus is omitted. When it is considered that these are estimates upon plants which have neither been located nor designed, a variation of 35% in the cost per horse-power on the same type of machinery is not unreasonable; the variation in the aggregate cost is mostly due to the 200% variation in the amount of horse-power recommended as necessary.

Question 21.—Give estimated cost for operating power plant, with coal at $1 per ton.

Question 30.—How much will it cost to operate this system per mile, per motor and per car, and also per passenger per mile?

Without repeating details the various estimates were:

Mr. Davis.

	Hours run.	Average horse-power.	Total horse-power.	Operating Cost per Year.	
				Total.	Per average horse-power.
(*a*)	..	....	12 800	$60 000	....
(*b*)	18	7 500	10 000	225 000	$30
(*c*)	18	Coal and labor only.	5 000	52 560	....
(*d*)	18	2 666	5 000	96 794	36
(*e*)	18*	Depreciation and repairs omitted.	15 000	222 650	....

* In the case of *e* the figures have been interpolated from 12 hours to 18 hours per day, adding $190 per day for the additional time.

Again the variation in operating expenses is due to the large differences in the estimated average power required.

The Thomson-Houston Company gives the cost of motive power as follows per car-mile: Station, 0.0069 cent; line, 0.0005 cent; motors, 0.0088 cent; total, 0.0162 cent.

a estimates cost of operating per locomotive-mile. 9–10 cents.
b " " " " car-mile..... 12.5 cents.
d " " " " " at..... 0.0112 cent.

The above strongly indicates the unreliable and inaccurate nature of the data given; *a* does not make it clear what part of the question is answered; *b* is the only clearly stated answer; while *c* and *e* do not reply, and *d* gives 0.0112 cent as the cost per car-mile, which, however, only includes station power and line transmission.

Question 23.—What is the best method of transmitting power from power house to motors?

Question 24.—If by the use of conduit, give estimated cost. If by the three-rail system, give cost. If by the overhead trolley system, give cost.

Question 25.—If the overhead trolley system is used, what is the best method for supporting wire, and how far should the supports be apart?

Question 26.—(1) What size should trolley wire be? (2) What size should feed wires be, and what distance apart should they feed into the trolley wire? (3) Give probable cost of repairs and maintenance of three systems.

Question 42.—What will be the percentage of loss in power between the steam engine and the motor?

The companies were unanimous in recommending the overhead trolley. It would be interesting to see what views they would express to-day, based upon experience in the use of a third rail on elevated systems, underground conduit work on surface street roads, the failure of special trolley work on the New York, New Haven and Hartford

Mr. Davis. Railroad, and the latter's only moderately successful use of the third rail on tracks which are not elevated.

a makes the total efficiency about ..... 57.5 per cent.
b " " " ..... 51.1 "
c " " " ..... 63.7 "

(According to figures, although total is stated at 50 per cent.)

e makes the total efficiency about..... 85.0 cents.

The estimated costs vary even more than other figures given. They are tabulated below, some of the amounts having been calculated from data given in answer to other questions :

	Cost of				Number of trains.	Kind of work.
	Overhead line.	Feeders.	Rail return.	Total.		
(*a*).....	.....	.....	.....	150 000	40	Wooden center pole.
(*b*)....	19 000 22 000	112 000 150 000	.....	131 000 172 000	50	" " "
(*c*).....	10 000	75 000	37 500	122 500	..	" " "
(*d*).....	.....	6 039	.....	40 000	40	" " "

	Size of trolley wire.	Feeders tap in every	Repairs.	Loss in line.
(*a*).....	00	2 640 ft.	None.....	20 per cent.
(*b*).....	00-000	500 "	5 per cent. of cost	15 "
(*c*).....	0000	100 "	.....	18 "
(*d*).....	00	....	9.5 per cent. of cost.....	20 "
(*e*).....	.....	500 ft.	3 per cent. of cost	7.5 "

Rail return work was apparently not included, except in one case, so that, should it be added to the other figures, at the estimated cost as given by *c*, there is a variation of 423% in total cost, and 166% in loss in line. Taking two-braid weather-proof 0000 wire weighing 671 lbs. per 1 000 ft., and 15 cents per pound as the price of wire at that time, and cost of stringing, cross-arms, insulators, etc., at 1 cent a pound (approximate), *b* must have estimated on about the equivalent of 1 596 000 ft. of 0000 wire, while *d* proposed using only 60 000 ft. of the same size wire. Had *b* obtained an average loss of 15% with the amount of copper proposed, 1 071 428 lbs., what would *d* have obtained with only 40 260 lbs.? *b* was figuring on 25% more trains. The average horse-power per train is given by *b* as 100 in the answer to this question, and 170 in the answer to Questions 18, 19 and 20. *d* gives it as 66.5 H.-P. The former recommended 150 to 200 H.-P. per car as equipment. and the latter, 100 H.-P. Assuming 100

H.-P. as correct, in the first case, *b* estimated on 50% more power per train than *d*. The loss in line, in this case, would be directly as the power, and, if the loss is doubled, the weight of copper is reduced to one-quarter; therefore *d*, assuming that *b* has estimated the loss correctly, seems to have figured on a drop of about 30%, although stating it to be only 20% (remembering that *b* proposes one power house, and *d* two, therefore halving the feeding distance in the latter case). Other discrepancies appear in the answers. *a* expresses the opinion that it costs nothing to maintain line work, while *e* has little to say on the subject. Mr. Davis.

Question 31.—Is there any electric line in operation similar to the one under consideration?

As stated in the answers, there were none; nor are there any to-day, although some of those at present in operation more nearly approach the conditions of the Illinois Central Railroad. In the year 1892 the first serious attempts were made to build cross-country trolley roads of high speed, operating on schedule times similar to steam railways. Among the first of these, designed and built by the writer as chief engineer, was the Washington, Alexandria and Mount Vernon Electric Railway, about 10.5 miles long, upon which was made a time of 22 minutes from terminal to terminal, or about an average of 35 miles an hour exclusive of stops. This was done with single-reduction double W. P. 50 Thomson-Houston Company motors, double-truck 34-ft. cars pulling one trailer of similar size. The generators were two 150 kilowatt bi-polar, Edison type, belt driven by Greene condensing engines, and steam was furnished by return tubular boilers. In the operation of this system the writer tested a single motor car with and without a trailer. Without giving the details, a train often took over 200 amperes (134 H.-P. at 500 volts) for a time, while the maximum loads never exceeded 67 000 lbs., and the speed with this load about 20 miles per hour. This road could not be compared with the problem under discussion, but these figures indicate that the motor equipments proposed would not have done the work required of them.

Question 34.—Is it possible and practicable to carry from 20 000 to 30 000 passengers per hour with electric power under the conditions named?

Question 35.—Is it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893?

Question 36.—How soon will it be necessary to award the contract for the above plant in order to have the line ready for operation by March 1st, 1893?

Question 37.—Would your company guarantee, on your own specifications and at an agreed price, the successful installation and operation of this plant by March 1st, 1893, with guaranteed capacity of 20 000 people per hour in one direction?

Mr. Davis. These were all answered in the affirmative except the last question, answers to which were omitted by *c* and *e*. The daring and enterprise of the electric companies was surprising when it is considered that what they proposed to undertake was to design and build motors, trucks or motor connections to existing standard trucks, generators and the hundred and one modifications in existing devices of switchboards, wiring, etc. However, an analysis of the data given by them evidently could not have encouraged the engineering department of the Illinois Central Railroad Company to make the change.

Question 41.—What is the proper size of wheels for motors and for trailers?

a recommends 42 in. for motor cars; 33 in. for trailers.
b " 42 " " " 33 " "
c " 30 " " " 30 " "
e " 48 " " " 48 " "

		Axle Revolutions Per Minute at Given Miles Per Hour.				
	Circumference of wheel in feet.	30	30	35	40	50 miles per hour, or
		1 760	2 640	3 080	3 520	4 400 ft. per minute.
		22.5	15.0	12.8	11.25	9.0 Express time, minutes, Van Buren St. to World's Fair.
(*a*).....	11	160	240	280	320	400
(*b*).....	11	160	240	280	320	400
(*c*).....	7.8	225	337	393	450	562
(*e*)	12.5	140	210	245	280	350

At the time of the World's Fair the average time from Van Buren Street to the exposition grounds was 12 minutes, or an average of about 37.5 miles per hour for express service. This would indicate that at times nearly 50 miles per hour was attained by steam locomotives performing this service, so that the entire electrical equipment proposed at that time would have been much too light to perform the actual work done later by steam.

The axle speeds are given in the table. If the ratio was four between armature and axle, low for motors at that time, the motor speed would have been such that those proposed could not have maintained the required train speeds.

The preceding analysis of the answers leads to the following main conclusions:

A large part of the apparatus would have been built new. As the design of electrical appliances is, even to-day, more largely experimental than in almost any other branch of engineering, it was unlikely that the attempt would have been highly successful.

Estimates of initial costs and of operation were only approximate and evidently very inaccurate. Mr. Davis.

The motor equipments proposed would not have been able to handle the express service to the exposition grounds.

The adoption of electric traction would have resulted in loss of business due to slowness of trains as compared to what was done with steam locomotives.

Although the change would undoubtedly have been made in time and the road would have operated and carried an enormous number of passengers, yet the net results would have been a failure, so far as the Illinois Central Railroad Company was concerned.

JOHN FINDLEY WALLACE, M. Am. Soc. C. E.—The discussion of this paper has been rather along general than specific lines, presumably because few installations of electric power even approaching so heavy a service as is required by the suburban traffic of the Illinois Central Railroad are in operation. As illustrating the service of the Illinois Central Railroad in comparison with that of two electric elevated roads, the accompanying speed diagrams (Fig. 4) are submitted. In the case of the Illinois Central, the total train-load was 260 000 lbs.; in that of the Metropolitan Elevated, the load was 100 000 lbs., and in that of the Lake Street Elevated the load was 120 000 lbs. It will thus be seen that the Illinois Central suburban service is much heavier than that of the other roads exemplified, both as to weight of train and speed attained. A study of these diagrams will develop the advantage of reduction of dead load hauled as compared with load of passengers, which at best is but a small fraction of the total. This reduction of dead load seems to be one of the principal advantages of traction by electric power. To attain the speed required by the Illinois Central schedule, the power applied to the hauling of the elevated train illustrated would require to be considerably increased, taking into account both the elements of maximum speed attained and the distances between stops. Mr. Wallace.

The powerful character of the suburban engines of the Illinois Central is indicated by the data given in the paper, and the speed diagrams show that these engines are being worked to their full capacity, and of necessity beyond their maximum economy in the production of power. The fuel consumption runs something over 90 lbs. of Illinois coal per train-mile.

The increase of the number of trains involved in changing the present system of heavy trains to that of one, two or three car trains, including motor cars, introduces the question of allowable speed under short headways. Powerful motors would naturally be required in order to accelerate quickly, so making any schedule called for with the least expenditure of energy. Fig. 5 shows the maximum speeds required to be attained for different distances of

Mr. Wallace.

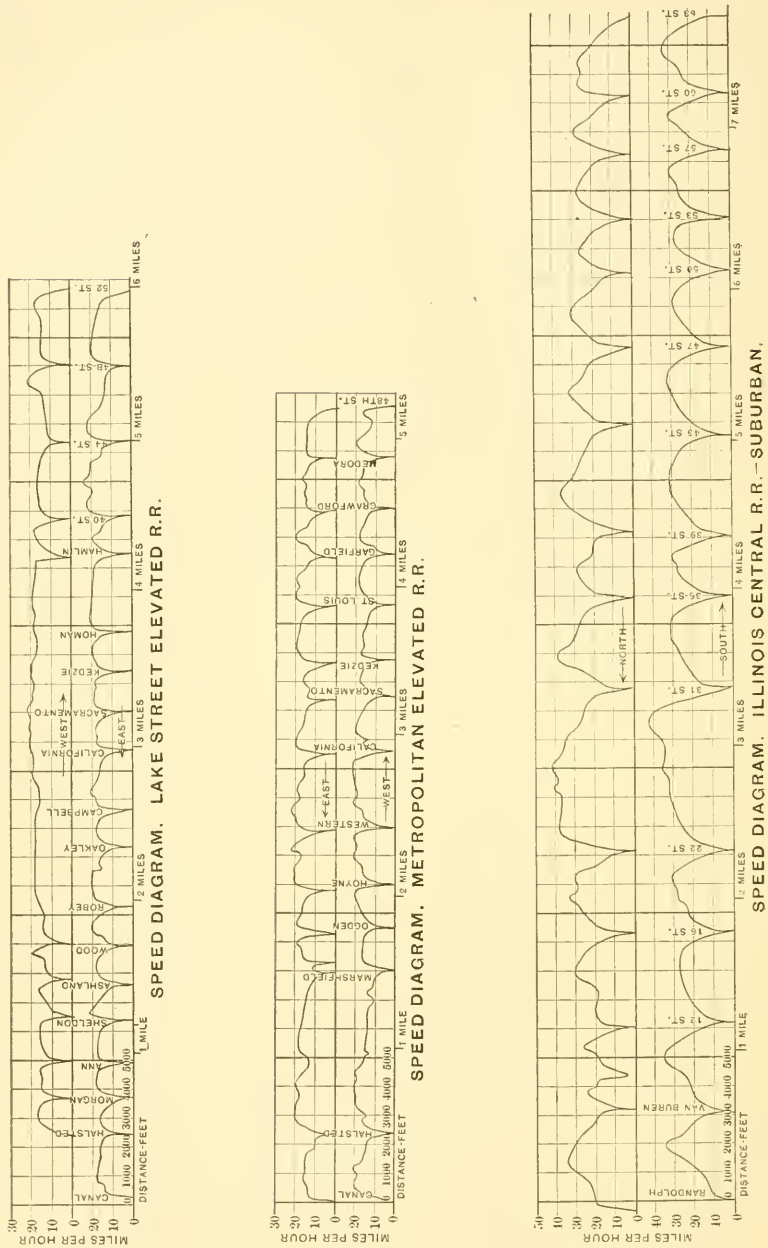

FIG. 4.

acceleration and retardation between stops for various time schedules between Randolph and Sixty-third Streets, the limits of the local suburban service as distinguished from the express. It will be noticed by examination of the diagram that the principle of quick acceleration involving less expenditure of total energy is well illustrated, see- Mr. Wallace.

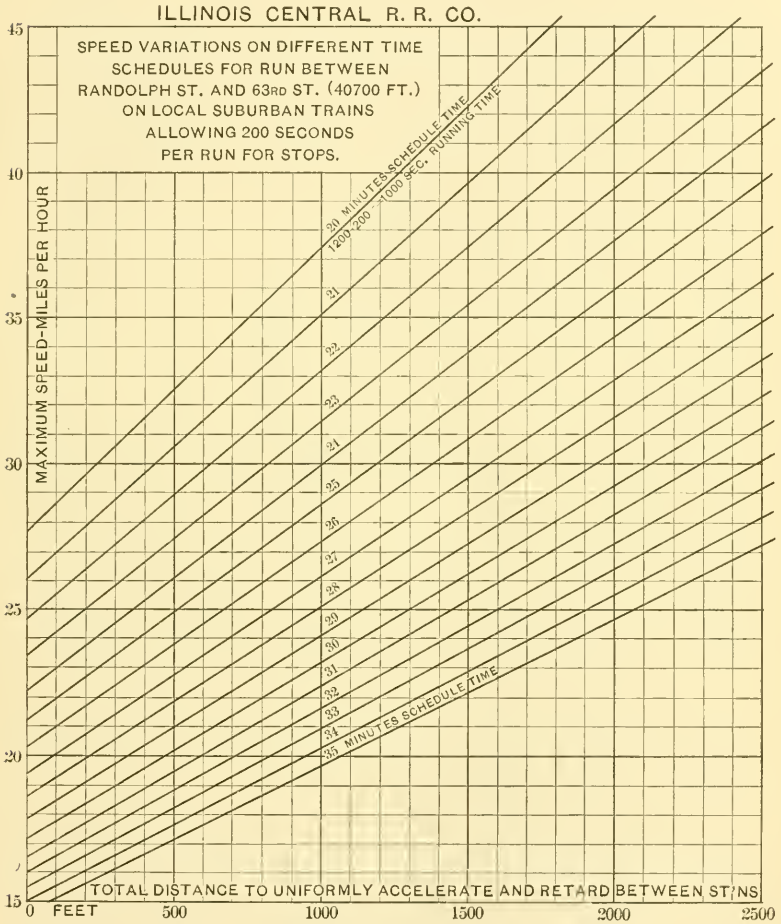

FIG. 5.

ing that total energy of acceleration varies approximately as the square of the maximum speed attained.

It is somewhat curious to note in the discussion of this paper the following diametrically opposed opinions:

Mr. Wallace. Mr. Clarke: "To make a city elevated railway a success, the surface elevated system must be copied and not the steam locomotive system of long trains at greater intervals."

Mr. Knight: "The direction in which progress lies is apparently in the line of larger trains moving more rapidly. The whole object of the elevated railway is speed, and speed cannot be had with short headways."

Perhaps the best reason which might be given for this difference of opinion is that each was considering different conditions of train-loading. One evidently had in mind a uniform loading, and the other was considering the exigencies of the morning and evening rush. Fig. 6 illustrates the conditions holding on the Illinois Central local suburban service during an average day; the maximum number of passengers carried per minute on the peak of the evening load being called

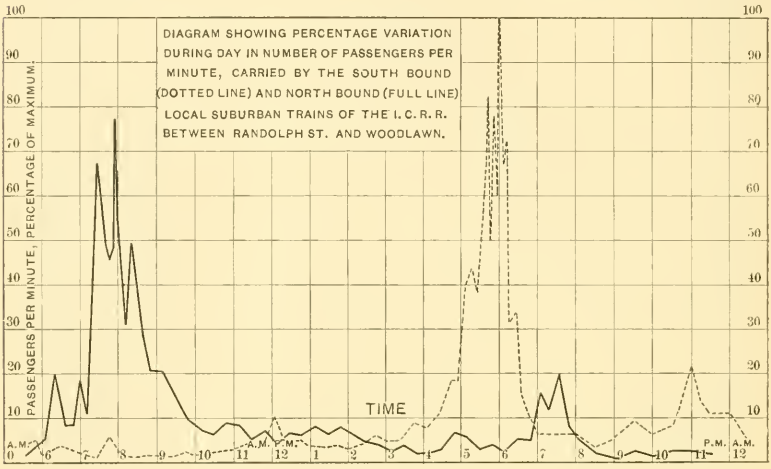

Fig. 6.

100 for convenience, and the number carried per minute at other times of the day being indicated by a percentage of this assumed maximum. Figs. 7, 8 and 9 indicate the number of cars per hour in service on both local and express trains.

Taking care of the peak of the load is of the utmost importance, as in the morning and evening rapid transit is more urgently called for than at any other time. The heavy draft of power and the violent fluctuations of load on the power house during the evening peak constitute one of the main difficulties to be contended with in an electric installation, as much of the machinery generating power at that time is idle during the greater part of the day. Whether the storage battery will solve the difficulty or not is more or less a matter of speculation so far as a service such as that of the Illinois Central is concerned.

Mr. Wallace.

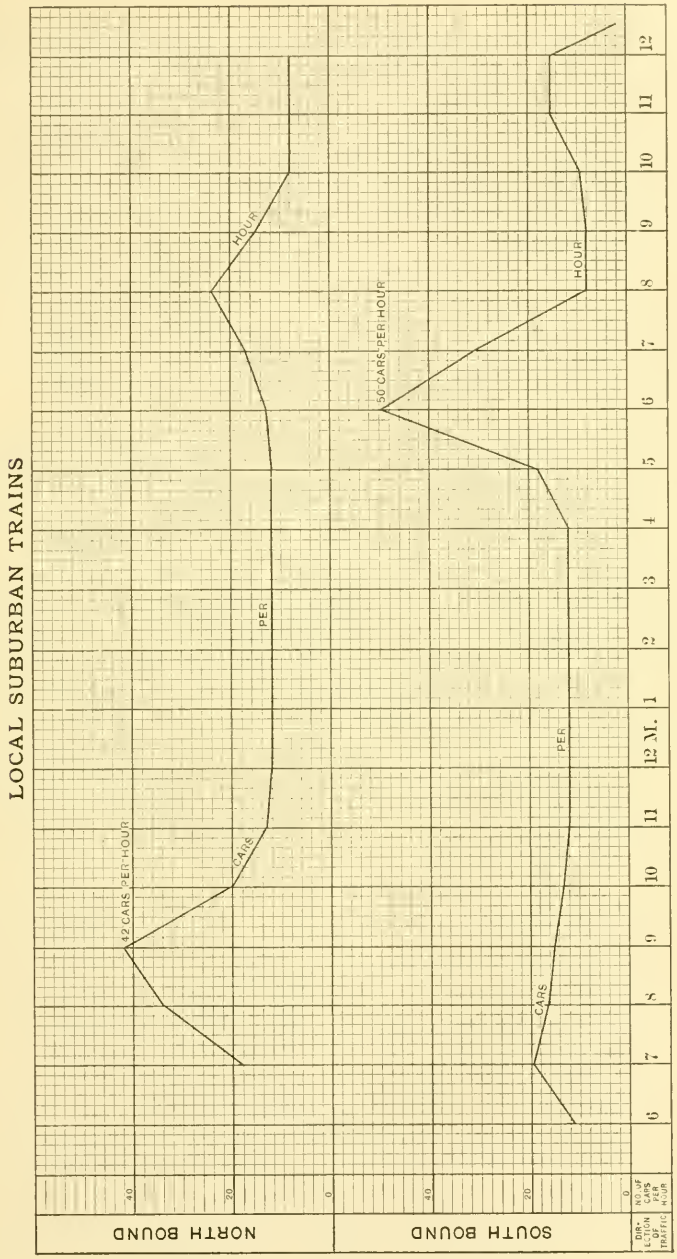

FIG. 7.

Mr. Wallace

The wide differences of opinion among electrical experts as to the cost of an electrical application at the present time as well as in 1892 is due largely to the differences in their ideas as to the details of power and speed requirements. Slow speed and a greater distance in which acceleration is permissible in order to obtain the maximum speed, are important factors in the matter of cost.

Mr. Clarke says: "The author should have added that the electric system is better adapted to frequent stops, and the steam locomotive to stops far apart." This is not necessarily the case. While it is true, as the author has heretofore stated, that the electric system is adapted to small units of transportation moved at frequent intervals, and the steam locomotive is adapted to large units of transportation moved at less frequent intervals, it does not necessarily follow that the electric system is better adapted to frequent stops inside of certain limits.

The author does not agree with Mr. Clarke in his statement that the tendency in the future of city elevated railways will be towards light structures, carrying light and very frequent trains, with motors on the cars themselves, for the reason, as he previously stated, that the preference for elevated roads shown by the public is only due to the increased speed of the latter over the surface lines, and increased speed cannot be obtained on elevated roads with the lighter equipment which Mr. Clarke has in view, particularly on account of the fact that the greater volume of traffic on lines of this character is concentrated within comparatively short periods of time, and the maximum number of people cannot be handled during these busy hours with small, frequent units of transportation. On the contrary, it will be necessary, especially if the business increases still further, to enlarge the size of the units as well as their frequency, to provide for a safe headway between trains in order that they may be run at greater speeds than now, at the same time enabling them to carry the greater number of people within the minimum period of time.

The author, however, thoroughly agrees with Mr. Clarke when he says that the main advantage of electric motive power is the fact that it will provide more frequent service at those hours of the day when travel is light, in order to stimulate business by giving increased convenience, and the ability to do away entirely with regular schedules for the running of trains. This remark applies particularly to the conditions existing on the Illinois Central Railroad.

The economy of the system is due to the fact that electric traction costs less per unit where it is desired that the units be small, than does steam locomotion for the same service. While it is true that traction is a very important element, the weight of powerful electric motors increases in such proportion that additional traction is also furnished. The author does not wish to be understood as favoring electric loco-

Mr. Wallace.

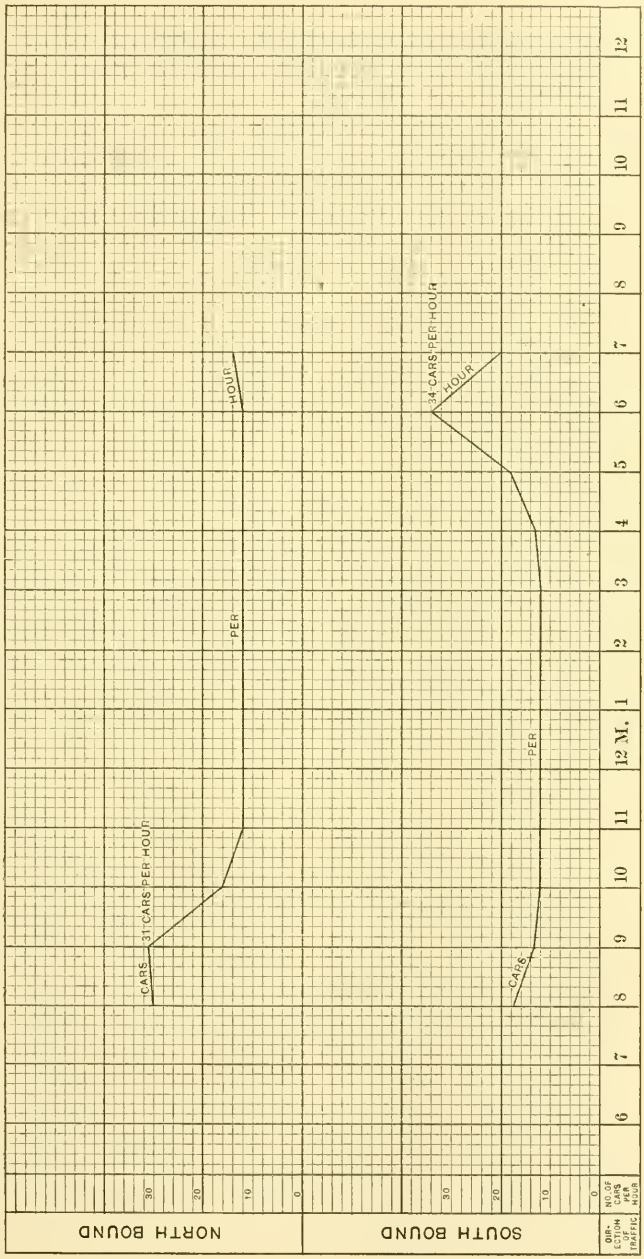

FIG. 8.

Mr. Wallace. motives, but his investigations so far incline him to prefer motor cars of sufficient power and weight to haul trailers; these motor cars, however, to be provided with the maximum seating capacity for passengers possible.

One of the practical difficulties in the way of placing motors on each axle of the car and on several cars of the train, and coupling them up so that they can all be used and under the control of one motorman, is that, so far as the author's investigations have gone, there is as yet no perfect and adequate controller in use in the United States which will provide for the proper manipulation of more than two motors. In the recent inquiries which he has made, he has endeavored to find a controller that would operate four motors under one car, that is, one on each axle; and found that the two-motor controller was virtually the limit of present practice in the United States. While electric companies claim to have controllers to operate four motors on the axles, the motors are only two two-motor controllers. This problem has evidently not yet been solved.

Mr. Prout states that it is "improbable, in the light of present knowledge of the subject, that the traffic now handled by steam traction, if carried in the same manner and at the same intervals, could be handled cheaper by electricity." He is correct in this statement. In the Illinois Central local suburban application over that portion of its service between Randolph and 63d Streets, it developed that a comparatively small economy would result from the substitution of electric for steam locomotives on the present schedule and with the present units of transportation, but it was shown that to give the frequent service desired and contemplated under the electric application, a large saving would be effected by the use of electric power.

In regard to his statement relative to the difference of opinion between the former and present general managers of the Manhattan Elevated Railway as to the economy of the electric application, the mere fact that two gentlemen of such wide experience in transportation matters should differ in opinion is in itself satisfactory evidence that electrical engineers have yet much to learn in regard to railroad conditions, and that their statements are based more on their individual beliefs as to what can be done than upon actual facts and figures.

Since the paper was written, the author has been giving close attention to the study of this problem as applied to the Illinois Central local suburban service. It has been found that the requirements on the Illinois Central as to speed and acceleration are approximately double those of any practical application of electricity to a similar service to-day, and that the principal electric companies are, to a large extent, still groping in the dark as to the proper and economical solution of problems of this kind.

Mr. Wallace.

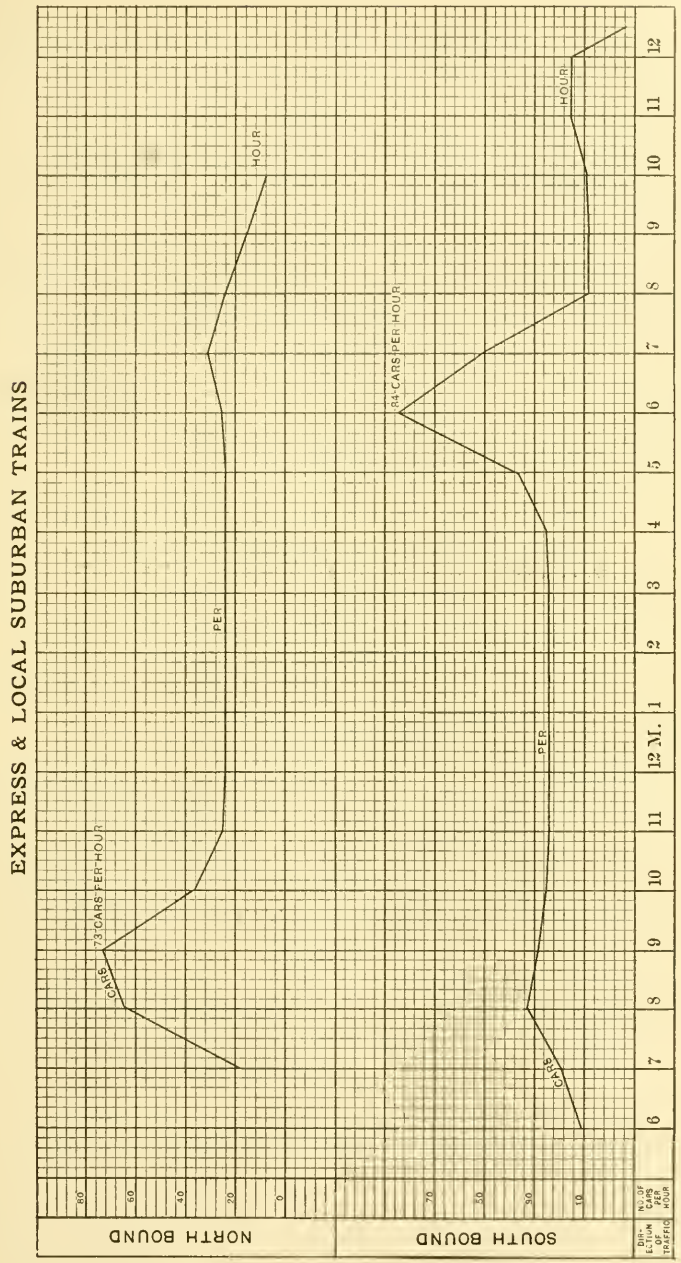

FIG. 9.

Mr. Wallace. It may be of interest to know the manner in which this investigation is being conducted by the Illinois Central Railroad Company. The matter has been placed by the management in the hands of an advisory board consisting of the general superintendent, the chief engineer and the superintendent of machinery. This board has employed John Lundie, M. Am. Soc. C. E., as an engineering secretary and expert, with proper assistants, to carry on the investigations and examinations and report to the board. Every detail of the problem is being carefully looked into and analyzed. The substitution of electricity for steam will undoubtedly be made if the results of these investigations demonstrate that the electric service will be as economical and efficient as the present steam service. The principal object of the change is to secure a more frequent service during the hours of light traffic, if it can be done without materially increasing the expense of operation, in the hope that thereby business will be increased. A minor object is, of course, to avoid the annoyance of smoke and steam, as the line runs through a high-class residence portion of the city.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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No. 804.

THE COMPRESSIBILITY OF SALT MARSH UNDER THE WEIGHT OF EARTH FILL.

By EUGENE R. SMITH, Jun. Am. Soc. C. E.

PRESENTED MARCH 17TH, 1897.

WITH DISCUSSION.

The importance of the dredging interests in and about the great cities of the sea coast cannot easily be overestimated; the very existence of the harbors and channels through which intercourse with the outside world is carried on, as well as the locations of piers and warehouses for the convenience of this intercourse, is often dependent upon the efficiency of the dredge. The methods formerly employed were comparatively expensive, and the work was confined to the improvement of the more necessary channels and the filling for the more important docks, warehouses and railroad terminals where the great business transactions warranted large outlays of money.

The present reduced cost of dredging due to the introduction of hydraulic methods makes practicable many plans of real estate development, which up to the time of these improvements could not be considered because of the prohibitory cost. Among these projected plans is the reclamation of tracts of marsh or meadow land bordering the salt water creeks and bays in the vicinity of cities and large towns.

The extent of such marsh land which might be made valuable for both business and residential purposes in the vicinity of New York may be appreciated when it is considered that within a radius of 15 miles of the City Hall the area of such land is three times as great as that of Manhattan Island.

The growth of the cities and the increasing demand for summer homes, together with the reductions in the cost of dredging, open an important and comparatively new field for both the engineer and contractor in the reclamation of these lands, not only about New York, but near every large center of population on the Atlantic seaboard. From the standpoint of the engineer one question of interest in an investigation or report on such a proposed work is the compressibility of the marsh under the weight of the requisite filling material.

During the fall of 1894 an opportunity was afforded for obtaining information on this question; the author was called upon to prepare a specification and solicit bids for the reclamation of 80 acres of such marsh land on the north shore of the Great South Bay, opposite Fire Island Light, at Islip, Suffolk County, N. Y. The underlying material is sand and gravel, with occasionally a little clay, the surface of which slopes gradually from the lower edge of the adjacent upland to the bay. This marsh, locally known as "meadow," consists of a growth of various salt grasses on the surface of the mud just above the level of ordinary high tide. This mud is the accumulation of decayed seaweed and other vegetable matter, and, owing to its composition and location, is soft and compressible. The surface of this meadow sod is, so far as the author's experience and observation goes, practically level and just above ordinary high tide, 0.4 ft. in this case. This sod growth forms a kind of leathery covering over the mud, distributing the pressure due to the weight of the filling material above upon the mud below, and preventing it from breaking through and being replaced by the heavier sand. The pressure on the mud from the fill above tends to increase the consistency of the mud by squeezing out the water until a condition of equilibrium is reached. It is a matter of conjecture whether the water rises through the sand and adjacent meadow to the surface and is dried out by the air or oozes horizontally out to the bay and creek; probably it does both.

The average thickness of the meadow sod and mud is 4.3 ft., the maximum thickness being 9.5 ft.; the ordinary rise and fall of tide is 15 ins.

The specification called for a fill of earth to a height of 3 ft. above the original level of the meadow surface, the contractor to assume the responsibility for the compression of the meadow sod up to the date of completion of the total work. As the contract price was per acre of finished fill without regard to the compression of the meadow, the investigation as to the compression would have no bearing on this undertaking, but the opportunity for an examination of the matter was too favorable to be neglected.

The total area to be filled was divided into squares of 100 ft. At each corner a stake was driven through the meadow firmly into the underlying sand and gravel, and the top was sawed off at the 3-ft. grade level. A board about 1 ft. square, with a short stake nailed to one edge, was placed on the meadow surface at the side of each grade stake, the short stake being pushed into the meadow sod so that the board could remain where placed at the surface and not be washed out of position as the filling took place. The thickness of the meadow sod was ascertained by pushing down a half-inch iron rod to the sand, and the thickness of the filled material from the surface down to the board was similarly determined. By referring all elevations to the top of the grade stake, the amount of compression was readily ascertained. The whole area includes all kinds of meadow, from hard to soft, so that the result may fairly be considered as representative of meadow where the rise and fall of the tide does not differ materially from that stated.

The contract was awarded to a firm which used one hydraulic dredge, equipped with an 18-in. centrifugal pump, which was run at a maximum speed of 250 revolutions per minute. The suction and discharge were also 18 ins. in diameter. The filling material was almost entirely sand from the bay and from canals dug through the meadow; the sand was a very sharp quartz, which caused serious wear on the pump, which was finally obviated by the use of hardened steel linings. These protected the pump shell and could be readily replaced as they became worn. The weight of the filling material (sand) varies from 2 875 lbs. to 2 956 lbs. dry and from 3 037 lbs. to 3 118 lbs. wet per cubic yard, the wet sand being about 5½% heavier than the dry.

In the accompanying tables the percentages given are with reference to the thickness of the meadow, and where a percentage is noted, in order that its proper value may be apparent, the number of observations of which it is the average is noted. A subdivision as to thick-

ness is also made into five classes as follows: 1.5 to 3.5 ft. inclusive; 3.6 to 4.5 ft. inclusive; 4.6 to 5.5 ft. inclusive; 5.6 to 6.5 ft. inclusive. and 6.6 ft. and upward, so that any peculiarity due to different thicknesses might be disclosed. It is also proper to state that the averages are carried out to tenths of 1% in order that any ratio or tendency shown by the results might be more easily noted and studied, rather than with any idea of determining the actual compression with mathematical exactness to a fraction of an inch.

TABLE No. 1.—Percentages of Compression for Various Periods and Depths of Meadow.

Duration of Time.	Percentage of Compression and Number of Stations observed, for Thickness of Meadow Sod as Shown Below.											
	1.5 to 3.5 ft. Av., 2.7 ft.		3.6 to 4.5 ft. Av.. 4 ft.		4.6 to 5.5 ft. Av., 5 ft.		5.6 to 6.5 ft. Av., 5.9 ft.		Over 6.5 ft. Av., 7.9 ft.		For all thicknesses combined.	
	Per-cent.	No. sta.	Per-cent.	No. sta.	Per-cent.	No. sta.	Per-cent.	No sta.	Per-cent	No. sta.	Per-cent.	No. sta.
1 mo....	7.7	49	10.6	47	11.7	37	10.0	20	10.9	19	10.0	172
2 mos...	10.1	49	14.2	47	14.8	37	12.8	20	14.8	19	13.1	172
3 mos...	11.8	48	15.0	43	16.4	36	12.8	17	16.5	19	14.3	163
4 mos...	12.3	47	16.0	43	17.1	36	13.8	17	17.5	19	15.1	162
5 mos...	12.5	47	16.4	43	17.6	36	14.4	17	18.2	19	15.5	162
6 mos...	12.9	45	16.9	39	18.1	34	14.0	11	18.6	19	15.9	148
7 mos...	13.5	43	17.4	36	19.4	28	15.7	9	19.4	19	16.7	135
8 mos...	13.1	39	17.7	27	20.2	25	17.4	7	20.1	15	16.9	113
9 mos...	12.6	36	17.9	22	19.7	17	17.7	7	20.7	14	16.6	96
10 mos...	10.9	32	17.0	19	20.0	12	18.3	6	21.6	13	16.2	82
11 mos...	11.1	25	17.8	13	20.8	10	24.0	2	22.0	13	16.7	63
12 mos...	11.1	21	20.5	4	22.8	6	26.0	1	27.6	6	16.9	38

TABLE No. 2.—Distribution of the Total Percentage of Compression Throughout the Successive Months, for All Thicknesses Combined.

No. of stations.	Total percentage of compr.	1st mo.	2d mo.	3d mo.	4th mo.	5th mo.	6th mo.	7th mo.	8th mo.	9th mo.	10th mo.	11th mo.	12th mo.
12....	22.4	10.2	5.0	2.8	1.0	1.0	0.7	0.1	0.6	0.1	0.4	0.3	0.2
34....	16.5	7.9	3.3	2.1	0.7	0.2	0.6	0.7	0.0	0.2	0.4	0.3	0.1
38....	16.9	8.3	3.4	2.2	0.5	0.3	0.5	0.3	0.3	0.4	0.3	0.1	0.3
63....	16.7	8.3	4.0	1.4	0.6	0.3	0.4	0.4	0.3	0.3	0.3	0.4	.....
82....	16.2	8.0	3.6	1.5	0.9	0.2	0.7	0.3	0.3	0.3	0.4	.....	.....
96....	16 6	9.0	3.3	1.6	0.8	0.3	0.5	0.4	0.3	0.4	.....	.....	.....
113....	16.9	9.7	3.3	1.5	0.8	0.3	0.5	0.4	0.4	.....	.....	.....	.....
135....	16.7	9.7	3.2	1.3	0.8	0.4	0.7	0.6	.....	.....	.....	.....	.....
148....	15.9	9.6	3.2	1.3	0.8	0.3	0.7	.....	.....	.....	.....	.....	.....
162....	15.5	9.8	3.1	1.3	0.9	0.4	.....	.....	.....	.....	.....	.....	.....
162....	15.1	9.8	3.1	1.3	0.9	.....	.....	.....	.....	.....	.....	.....	.....
163....	14.3	9.8	3.1	1.4	.....	.....	.....	.....	.....	.....	.....	.....	.....
172....	13.1	10.0	3.1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE No. 3.—Comparison of Average Compression with Compression for Thin, Medium and Thick, Meadow.

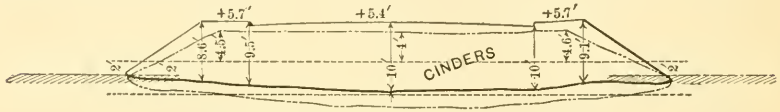
Duration of Time.	General Average See Table No 1.		Thin Meadow. 1.5 to 3.5 Ft. inclusive. Average Thickness = 2.7 Ft.			Medium Meadow. 3.6 to 6.5 Ft. inclusive. Average Thickness = 4.7 Ft.			Thick Meadow. 6 6 Ft. and Upward. Average Thickness = 7.9 Ft.		
	Number station.	Percentage.	Number station.	Percentage.	Variation from general average.	Number station.	Percentage.	Variation from general average.	Number station.	Percentage.	Variation from general average.
1 mo....	172	10.0	49	7.7	— 2.3	104	10.9	+ 0.9	19	10.9	+ 0.9
2 mos...	172	13.1	49	10.1	— 3.0	104	14.1	+ 1.0	19	14.8	+ 1.7
3 mos...	163	14.3	48	11.8	— 2.5	96	15.1	+ 0.8	19	16.5	+ 2.2
4 mos...	162	15.1	47	12.3	— 2.8	96	16 0	+ 0.9	19	17.5	+ 2.4
5 mos...	162	15.5	47	12.5	— 3.0	96	16.5	+ 1.0	19	18.2	+ 2.7
6 mos...	148	15.9	45	12 9	— 3.0	84	17.0	+ 1.1	19	18.6	+ 2.7
7 mos...	135	16.7	43	13.5	— 3.2	73	17.9	+ 1.2	19	19.4	+ 2.7
8 mos...	113	16.9	39	13.1	— 3.8	59	18.7	+ 1.8	15	20.1	+ 3.2
9 mos...	96	16.6	36	12.6	— 4.0	46	18.5	+ 1.9	14	20 7	+ 4.1
10 mos...	82	16.2	32	10.9	— 5.3	37	18.4	+ 2.2	13	21.6	+ 5.4
11 mos...	63	16.7	25	11.1	— 5.6	25	19.5	+ 2.8	13	22.0	+ 5.3

Note.—In taking the average percentage of compression for all thicknesses, it is assumed that it is independent of the thickness of the meadow. This is not strictly correct, the percentage of compression for thin meadow being less than, and for thick meadow more than, for the general average as shown above for all thicknesses.

Some experience of the author in Jamaica Bay during 1896 on the same kind of work shows the percentage of compression to be materially less where the rise and fall of the tide is greater (4 to 6 ft. in Jamaica Bay), other things being equal. The information there obtained was not sufficiently extensive to authoritatively warrant any more definite statement than this; the same relative level, practically, is maintained between the surface of the meadow and ordinary high tide, and it is suggested that the opportunity for drying out of the upper portion of the meadow sod during a part of each tide tends to harden the sod, and make it less compressible than where it is saturated all the time.

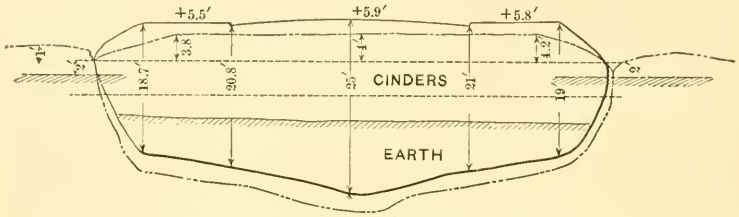
DISCUSSION.

Mr. McCann. THOMAS H. MCCANN, M. Am. Soc. C. E.—Between the original island of Hoboken, N. J., and the mainland there was at one time a branch of the Hudson River, which has been gradually filled up until its bed is now covered by a salt marsh with its surface about 2 ft. below the average high-water level. The depth of this marsh ranges from 30 to 100 ft., being generally greatest near the mainland. The material is a dark blue clay overlaid with silt and decayed vegetable matter. The numerous street improvements constructed over this marsh furnish some information of the same nature as that given in the paper. The



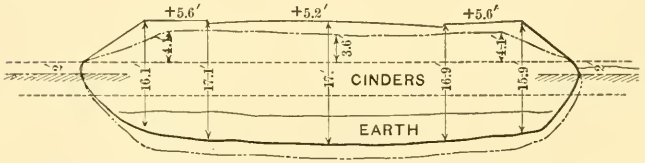
UNDERLYING MATERIAL; 56′ SILT, 10′ SAND, ROCK.

FIG. 1



UNDERLYING MATERIAL; 54′ SILT, 17′ SAND, ROCK.

FIG. 2



UNDERLYING MATERIAL; 61′ SILT, 17′ SAND.

FIG. 3

filling was done by contract at a fixed price per cubic yard, the quantity of material, usually boiler-house cinders, being ascertained by measurement on the scows and again by making borings and cross-sections of the streets. There was a difference of about 15% between the two measurements, which represents the shrinkage of the filling in the bank.

Three typical sections of one of these streets are presented in Figs. 1 to 3. The upper and lower dotted lines are the levels of high and low water respectively, the distance between them being about 5 ft.

Mr. McCann.

The surface elevation of the original meadow is indicated by the shaded line, and is 2 ft. below mean high water. The solid line gives a section of the new embankment as determined by borings, while the broken line shows the amount of settlement after three years. There is little displacement of the meadow at the sides of the fill where the latter is not more than 10 or 12 ft. deep, but where it reaches greater depths, the meadow is forced up. The street surface is generally 4 to 5 ft. above mean high water. At the point where the section in Fig. 2 was taken the embankment has settled about 2 ft., while the meadow has risen.

The streets were generally made by building a roadway in the center, and then widening the bank gradually to its full width, about 65 ft. This method of construction accounts, to some extent, for the greater depth of the fill in the center than toward the sides. There was no filling on the meadow alongside the bank. Fig. 2 is a section at a point where the first filling was done with earth from some cellars the contractor was digging. The street had about 10 ft. of this material on it when it sank suddenly 2 or 3 ft. during one night. The remainder of the fill was made with cinders. This section is among the deepest on the work.

It is well known that in filling a bank on marsh land three things occur: First, there is a compression and displacement of the lighter and softer marsh by the heavier filling; second, a shrinkage of the filling material and about the time the road is finished the embankment is floating, so to speak, on the marsh; third, the embankment settles gradually, compressing or displacing (in many cases doing both) the softer marsh. This settlement continues for many years, and, of course, is greatest in a road on which there is heavy traffic.

There seems to be no constant relation between the depth of the marsh and that of the filling. In hundreds of cross-sections of filling on marsh lands taken during the last thirty years, the speaker found the percentage between these depths to vary from 10 to 70. The three sections presented are from one street, and are within a few hundred feet of each other.

CORRESPONDENCE.

Mr. Clark. J. H. Clark, Assoc. M. Am. Soc. C. E.—In 1891–92, the writer was engaged at South Bend, Wash., on filling a tidal meadow for the Northern Pacific Railroad Company. About 160 acres were filled to a height of 3 ft. and 20 acres to a height of 5 ft., with sand excavated from the river. It was proposed to measure the settlement of the original surface by a method similar to that of the author, but there was no settlement up to the spring of 1893, when the writer left the work. Both bench and reference marks were carefully set. The average range of the tide at South Bend is from 6 to 8 ft., with a maximum of 16 to 18 ft. The meadow was composed of silt, resting on clay, and had a strong sod with no tendency to springiness in walking over it. It was intersected by innumerable tidal cuts which were filled with water every high tide.

Mr. Smith. Eugene R. Smith, Jun. Am. Soc. C. E.—The author made an effort to devise a quick test of the compressibility of the marsh, which might be of use in other tests, for purposes of comparison with this particular tract, in the hope that the information contained in the paper could be more fully utilized by engineers having similar problems to solve, but no satisfactory result was reached and the attempt was abandoned. If any method other than the exercise of the engineer's judgment is perfected at any time which will indicate with some reliability whether a particular tract under investigation is of the character, for instance, of the Hoboken marsh described by Mr. McCann, unreliable in the extent of its compression, or non-compressible, like that described by Mr. Clark, or like that at Islip, which has seemed to be governed to a certain extent by some law, engineers will be pleased to know of it.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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No. 805.

WIND PRESSURES IN THE ST. LOUIS TORNADO, WITH SPECIAL REFERENCE TO THE NECESSITY OF WIND BRACING FOR HIGH BUILDINGS.

By Julius Baier, Assoc. M. Am. Soc. C. E.

Presented March 3d, 1897.

WITH DISCUSSION.

Very destructive tornadoes have fortunately been infrequent, but the possibility of their occurrence at almost any time cannot be entirely overlooked in the design of structures of great magnitude and cost that may be exposed to their action.

On May 27th, 1896, St. Louis was visited by a tornadic storm that caused a loss of 255 lives and the destruction of property to the amount of $12 000 000. Much of the damage was the result of the direct action of the wind, and a few opportunities occurred to determine the intensity of the wind pressures which prevail in such storms.

This paper is presented mainly with the object of placing on record some definite estimates made by the author of the force exerted by the wind on several structures of known stability that failed under its action, and some further characteristic examples of destruction that

will be indicative of this force, even if its intensity cannot be definitely measured.

A study of the work of the tornado in some detail emphasized certain features as to the nature and action of the wind as a destructive agent, which appeared to be further corroborated by various experimental results.

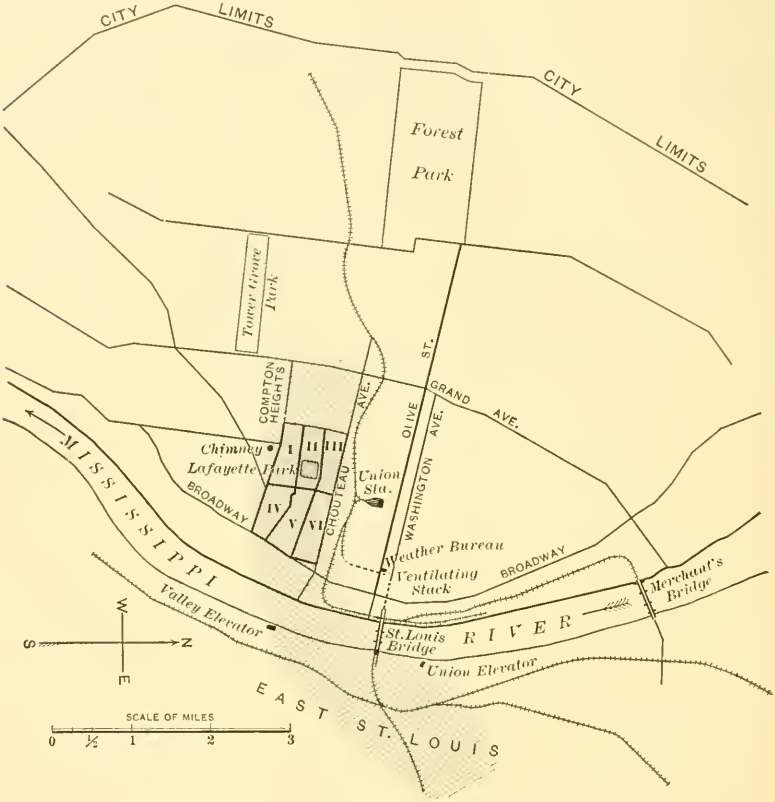

FIG. 1.

The possible effects of extreme wind pressures on high buildings will no doubt be variously estimated. The author has presented some conclusions that appear to follow logically from the evidence.

I.—General Conditions.

The storm entered St. Louis from the west, progressed eastwardly through the city at some distance south of the central business section,

crossed the Mississippi River and continued in a northeasterly direction through East St. Louis. The path of the storm, as marked by its destructive effects is indicated by the shaded section on the map, Fig. 1.

The meteorological conditions which attended the storm are given in

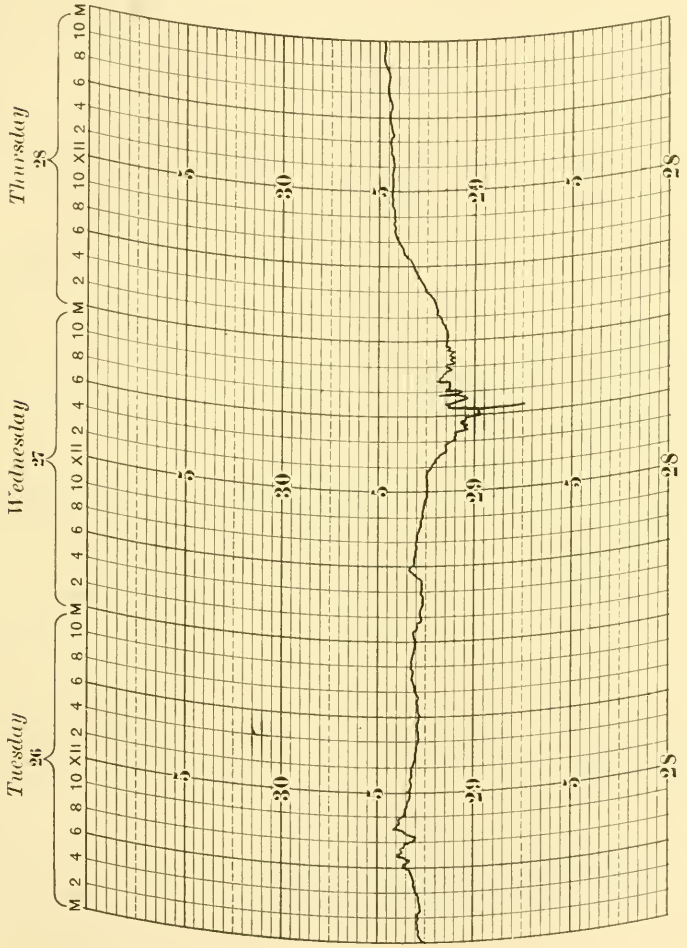

FIG. 2.

Appendix A as abstracted from the report of Mr. H. C. Frankenfield, Local Forecast Official in charge of the Weather Bureau Station. The latter is situated in the heart of the city, about a mile from the center of the path of the tornado.

The most marked feature of the storm was the reduction in the atmospheric pressure. The copy of the barograph trace in Fig. 2 is the record of the self-registering aneroid barometer at the station, and shows the general fall of pressure and comparatively low reading during the storm. The recorded pressures shown should have 0.6 in. added to them, to reduce to the sea-level datum. The fluctuations before and several hours after the storm indicate the unstable condition and greatly disturbed state of the atmosphere. As a matter of general interest the barometric record of the tornado which passed over Paris, France, on September 10th, 1896, is reproduced in Fig. 3. While noting the similarity of the lines, it is necessary to bear in mind that while the Paris Observatory was directly in the path of the storm, the records of the instruments at St. Louis show the conditions about a mile from the center of action and can give but an indication of the disturbance in the elements at that point. There was no barograph at the Louisville station on the day of the tornado there, March 27th, 1890.

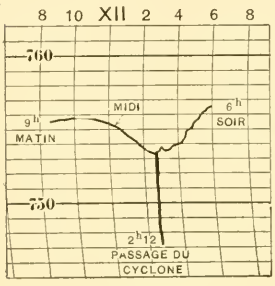

FIG. 3.

There is no record of the pressure in the path of the tornado except the reading of the aneroid barometer referred to in Mr. Frankenfield's report. This instrument was hanging at a window on the first floor of the house, and as the storm struck the building the index was noticed to be almost opposite to its usual position, or pointing nearly downward. As afterwards ascertained, this would give a reading somewhere between 680 mm. and 690 mm., and it is assumed here at an average of 685 mm. The author has since tested this instrument, comparing its readings at reduced pressure under an air receiver with a mercury gauge, and found the corrected pressure for a reading of 685 mm. to be 671 mm., equivalent to 26.63 ins. on the mercurial barometer locally, or 27.23 ins. reduced to sea level. This would give a difference in barometric pressure of 2.13 ins. below the lowest reading recorded at the time of storm at the Weather Bureau Station, and about 2.4 ins. below the average reading which prevailed at that point for some time preceding the storm, the latter reading being, however, about 0.23 in. lower than at noon. The house had the roof and part of the upper

walls taken off, windows broken, and the contents very generally blown about by the winds, but this damage occurred afterward. The barometer was accidentally noted, but not read, immediately preceding the general conclusion and excitement due to the extreme severity of the storm, and the result can probably be accepted with a possible error of say a tenth or two either way.

While the self-registering barometers record the variations of pressure corresponding to inches of mercury on the gauge to a full-size scale, the small scale of the abscissas allows but an approximate estimate as to the exact time of occurrence or the rate of this change. The horizontal scale being about 15 hours or 900 minutes per inch, 0.01 in., or about the thickness of a line, is equal to 9 minutes in time. A variation of pressure requiring a few minutes for its completion would leave the same record as one taking place in a few seconds.

The anemometer record shows the passage of 13 miles of wind in about 12 minutes; of this, a little over 6½ miles passed in 5 minutes, a rate of about 80 miles an hour observed, giving, when properly corrected, an actual velocity of about 62 miles per hour. The general direction was towards the south, into the storm center.

There are indications of a strong downward component to the wind at a point about 800 ft. northeast of the Weather Bureau Station at the ventilating stack* over the tunnel by which the trains over the St. Louis Bridge enter the city. The ventilating fan placed at the bottom of the stack, which is used to exhaust the smoke from the tunnel, was checked and the engine slowed down from its usual speed of 80 to 90 revolutions per minute to about one-third or one-fourth of that speed, for an estimated period of 10 to 15 minutes, by the pressure of the air above. The stack is 110 ft. high, 15 ft. in diameter and flared to 30 ft. diameter at the base to admit the fan; the latter is 20 ft. in diameter, revolves in a horizontal plane, and is directly coupled to the engine shaft by beveled gear. On opening the manhole just above the level of the fan to locate the trouble, the engineer was thrown across the room by the rush of escaping air.

The foregoing facts, coupled with the general indication and testimony of strong winds from the west, north and east, with the prevailing direction towards the general center of the storm, are well established. There was an apparent meeting of heavy clouds coming from

*See "Ventilation of Tunnels," N. W. Eayrs, *Transactions*, Vol. xxiii, p. 293.

opposite directions, followed by general darkness and a general storm of more or less violence. There were no funnel-shaped clouds seen so far as the author knows.

The general conditions which prevailed within the storm at its height were a total darkness except where relieved by the lightning and grounding of electric wires; furious wind, filled with flying missiles, that blew in turn apparently from every direction in puffs and gusts of extreme intensity and a continuous roaring noise that drowned every individual sound; the shock and crash which must have attended the fall of the Valley Elevator was not noticed by men within 100 ft. of the building. The time the storm occupied in passing any one point is generally given as very short, though this would depend, of course, upon the location of the observer. In one instance in a street car, at about the center of the area devastated by the storm, the time, noted by the watch, was between four and five minutes. During this interval the darkness was complete, and the wind blew in successive gusts and blasts that shook the car until it seemed in continuous motion.

The attendant confusion, terror and danger, and the immediate necessity of looking for shelter and personal safety, rendered all other matters of secondary importance, and, in general, little is known of the storm except its results. The full extent of the damage was often unknown, even to occupants of the house until the storm was over. When the destruction was noted, it was nearly always observed to be due to the successive action of the wind.

The débris, as a rule, offered but a confused and conflicting testimony as to the general direction of the wind. The great extent of the destruction, the immense volume of material moved, the confused condition due to the successive blowing about by the wind, and also the promptness with which much of the material was moved and piled up by corporations and citizens in clearing the streets and their property, largely destroyed the value of any deductions as to the successive action of the wind.

The great bulk of the material was carried only a short distance, from a few feet to several hundred, and there was apparently a marked absence of that continued carrying power of the wind so frequently found in tornadoes. This may have been due to the difficulty of identification, as any object carried a long distance would scarcely be

missed where it came from and not noticed or recognized where it fell, or such fact would probably be known only to a few persons.

There are members of this Society in St. Louis who, either from personal experience in the tornado or from immediate opportunities of noting results at the destruction of their homes, can give a more detailed account of results than can possibly be done by the author. A record of the evidences of extreme velocity or pressure of the wind, of which there were innumerable instances, would be of special interest if well verified. One evidence is afforded by a piece of pine plank driven by the wind through the $\frac{5}{16}$-in. web of a plate girder on the approach to the St. Louis Bridge, in East St. Louis. The uncertainty as to whether the plank was a detached piece or was fastened to a heavier frame at the moment of impact precludes even the most approximate estimate as to force or velocity.

A general inspection of the buildings brings out the following average characteristic features. The extreme force of the wind was generally confined to upper stories and roofs. The intensity of this force must have been extremely variable, not only as exerted on adjacent properties, but on a single building. There was very general evidence of the destructive force being exerted from the inside.

The total number of buildings destroyed or seriously damaged by the storm in the city of St. Louis, as shown by the records in the assessors' office, is 7 263. Of these 321 were totally wrecked. The number of houses slightly damaged that can be repaired at an average cost of $75 is 1 249, making a total of 8 515.

Aside from actual inspection, only photographs can convey any adequate impression of the appearance of these wrecked buildings. The church in Fig. 1, Plate II, has been selected as average example of maximum destruction, both as to intensity and area covered, the extreme destruction being generally very much localized. Instances of entire physical destruction are very few and nearly always due to a collapse on account of very old and weak construction; in general the damage is confined to the roofs and upper walls of the houses. The building in the foreground and the one on the right, in Fig. 2, Plate II, and the church in Fig. 1, Plate III, are cases of partial destruction presented to show some characteristic results of the action of the wind.

The general maximum destruction covers an area from 4 000 ft. to 6 000 ft. wide and nearly 3 miles long, lying immediately south of the central part of the city in St. Louis and extending across the river into East St. Louis. There was in addition much damage in several directions towards the west and at various places on all sides of this area. With the exception of a line of factories and industrial plants near the railway on the north and the river on the east, almost the entire area affected in St. Louis is used for residence purposes. A comparatively small section at the western limit and around Lafayette Park is built up with costly private residences. The rest of the buildings are of the cheaper class of brick dwellings, flats, tenements, and small factories, two and three stories high, built in the solid rows common in large cities, with only an occasional church, school or large commercial building standing above the general level. The western section is comparatively new, the eastern part from thirty to sixty years old, with some buildings along the river front that are still older.

Tables Nos. 1 and 2 show approximately the character of the buildings and the extent of the damage in a part of the district where the effect of the tornado was greatest. The district for which this data was compiled, extending from Broadway to California Avenue and from Chouteau Avenue to Russell Avenue, is enclosed by heavy lines on the map, Fig. 1, and divided into six sections. It is from 4 000 to 4 600 ft. wide, and 7 300 to 9 000 ft. long, covering an area of 1.33 square miles, and is divided into 183 city blocks about 260 × 300 ft., or double that size. The entire area is almost solidly built up, having a total number of 4 090 buildings, an average of about 22 per block; there are but 21 blocks having 10 houses or less per block.

Table No. 1.

Ratio of Damage to Total Value of House.

Value.	No damage.		0 to ¼		¼ to ½		½ +		Total Loss			
	No.	Per-cent.	No.	Per-cent.	No.	Per-cent.	No.	Per-cent.	No.	Per-cent.	No.	Per-cent.
$1 500 and less..	393	26	488	32	422	27	109	7	125	8	1 537	100
$1 500 to $3 000..	451	26	812	47	317	18	97	6	52	3	1 729	100
$3 000 and over..	210	26	390	47	145	18	61	7	18	2	824	100
Total.....	1 054	26	1 690	41	884	21	267	7	195	5	4 090	100

FIG. 1.

FIG. 2.

Table No. 2.

Section.	No. of City Blocks.	No damage.		0 to ¼		¼ to ½		½ +		Total Loss.		
		No.	Per-cent.	No.	Per-cent.	No.	Per-cent.	No.	Per-cent.	No.	Per-cent.	No.
I.....	22	91	18	237	47	120	24	38	7	21	4	507
II.....	16	26	7	125	36	114	33	52	15	31	9	384
III.....	30	135	20	217	32	201	29	71	10	63	9	687
IV.....	38	233	32	321	45	135	19	18	2	16	2	723
V.....	42	185	27	288	43	157	23	25	4	17	3	672
VI.....	35	384	33	502	44	157	14	63	5	47	4	1 153
Total...	183	1 054	26	1 690	41	884	21	267	7	195	5	4 090

In Table No. 1 the buildings are grouped according to their value; in Table No. 2 they are given according to locations. Sections 2 and 3, embracing Lafayette Park and the adjacent property, show the heaviest destruction. The assessors' lists from which the tabulations were made show that the 195 buildings totally wrecked are distributed in 72 blocks; that 31 of these blocks have each only one house totally destroyed, and the other 41 blocks have each from two to ten houses totally destroyed. The 1 054 houses not seriously injured are distributed over 153 blocks, there being 30 blocks in which no house escaped. In 19 blocks only one house in each escaped serious damage; in 34 blocks one-half of the houses, and in 11 blocks three-fourths of the houses, in each escaped. Throughout the path of the storm the buildings and wreckage show evidence of extreme and sudden variations in the intensity of the wind pressure. A striking example of this is a little pavilion left standing in Lafayette Park, on a slight elevation above the general level at a point where the broken and uprooted trees show the full force of the storm. A straw-thatched roof held in a light wire netting and perched on six uprights planted in the earth and stiffened by a few rustic braces, it would seem a most inviting mark for the wind, but except for some damage due to the falling limbs of adjacent trees, it stands uninjured.

II.—Force of the Wind.

The St. Louis Bridge.—The main damage sustained by the St. Louis Bridge was confined to the upper section of the masonry approach immediately adjoining the east abutment of the bridge proper.

The details of the construction of this part of the bridge are shown in Fig. 4. The structure is double decked, the highway floor, which is the full width of the bridge, being carried immediately above the railway tracks by cross-girders resting on the masonry side walls. These walls are 30 ins. thick, and are pierced by 21 arched openings, leaving a row of pillars 30 ins. square, spaced 8 ft. 7¼ ins. between centers. The masonry is built of sandstone, and is all first-class dimension work, all the blocks being the full thickness of the wall and laid with the bond shown on the drawing.

The highway floor is of timber carried on iron cross-girders. The sidewalks are 10 ft. wide, built of 3-in. planking, supported on 3 x 14-in. stringers, with a line of 7 x 14-in. stringers on the outside, to which the iron handrail is securely bolted. The roadway is 34 ft. wide, and consists of cypress block paving, 4½ ins. deep, laid on 3-in. cypress planking carried on 26 lines of 6 x 14-in. pine stringers. The planks are laid crosswise of the structure in two 17-ft. lengths, bringing all joints on the center line, and are spiked to the stringers. The latter are in lengths of two panels, and laid with lap joints. Six lines of these stringers are secured to each of the iron cross-girders by two ¾-in. bolts with special washers.

The iron girders carrying the floor are centered over the pillars of the side walls. Seven of these girders near each end were heavy 15-in. rolled I-beams supported at their central points by longitudinal girders, one at each end, to which they were fastened by braces. These longitudinal girders were 42 ins. deep and were supported on posts from the railway floor beneath, except the west end of the west girder, which was seated in a narrow recess cut into the masonry abutment for that purpose. Although the girder extended 2 ft. into this pocket, and the latter was 40 ins. deep, there was no abrasion of any kind on the stonework. The girder must have been raised out of the pocket by a straight lift, this being possible, as the fastenings of the floor to the iron girders were of sufficient strength to raise the weight of the latter. The 15-in. I-beams each weighed about 3 000 lbs. and the longitudinal girders each 13 000 lbs. To provide clearance and headroom for a cross-over in the railroad tracks, the seven girders near the center were made to span the full distance. They were built beams with 27-in. webs, and weighed about 8 000 lbs. each.

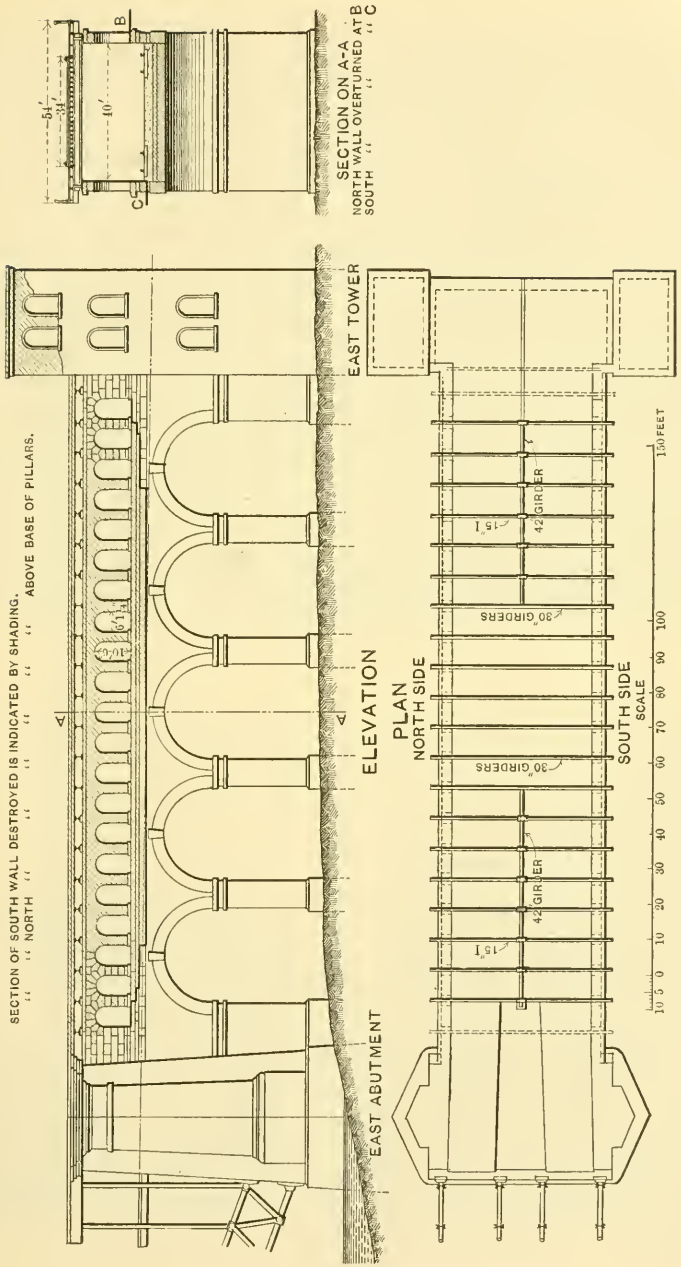
SECTION ON A-A
NORTH WALL OVERTURNED AT B
SOUTH " " " " C
54'
34'
10'
B
C
EAST TOWER
SECTION OF SOUTH WALL DESTROYED IS INDICATED BY SHADING.
" " NORTH " " " " " " ABOVE BASE OF PILLARS.
ELEVATION
PLAN
NORTH SIDE
SOUTH SIDE
SCALE
150 FEET
EAST ABUTMENT
15" I
42" GIRDER
30" GIRDERS

FIG. 4.

During the storm a rush of wind from the northwest carried away 200 lin. ft. of the highway floor with the girders attached, and overturned both sidewalls for a length of 180 ft. The highway floor for a distance of 100 ft. on the main span immediately adjoining this section was disturbed by the wind, the sidewalk being carried away, and the north half of the roadway being lifted and partly moved out of its place. The extent of the damage to the arcade is indicated by the shading in Fig. 4, and is shown in Fig. 2, Plate III, which is a view taken from the south side looking northwest, several days after the storm, the trestle work on the right being a temporary support for the roadway in process of erection.

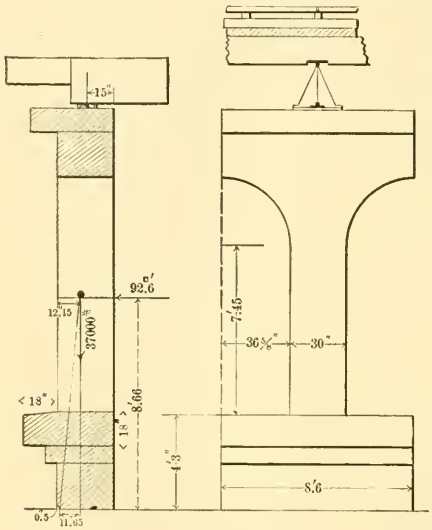

FIG. 5.

FIG. 6.

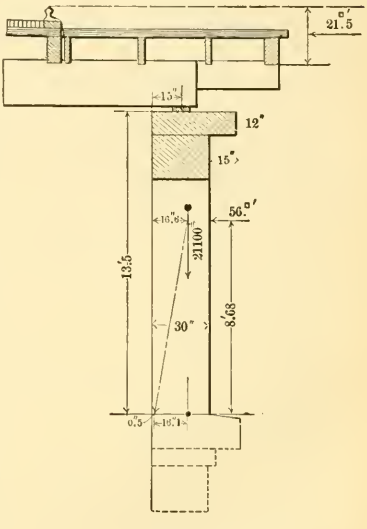

FIG. 7.

The following computations of the stability of the structure are made for two assumptions. First, that the floor was lifted, and then the walls overturned separately. Second, that the walls were overturned together with the full weight of floor upon them. In each case the wind is assumed to act at right angles to the face of the wall. The weight of the sandstone was found by the actual weighing of two blocks to be 140 lbs. per cubic foot. The cypress timber from an average of several planks was found to weigh $3\frac{1}{2}$ lbs. per foot B. M. The pine was assumed at $2\frac{1}{2}$ lbs. per foot B. M.

FIG. 1.

FIG. 2.

The overhang of the coping and sill-course brings the center of gravity of the wall near the outer face. This very markedly increases the stability as against falling inward and reduces it against falling outward.

The general dimensions and details of one panel are given in Figs. 5, 6 and 7. The weights, area exposed and centers of gravity have been computed from data given there. The limiting position for the center of pressure is taken $\frac{1}{2}$ in. from the edge as the stone shows very little crushing.

Floor Lifted and Walls Overturned Separately.

In estimating the weight of the floor, the handrail is to be included in the weight of the sidewalk, and the girders in that of the roadway. This gives the following weights per square foot of surface:

Sidewalk, including handrail.....		22.1	lbs. per square foot.
Roadway, end panels—timber.....	43.1		
girders.....	16.6		
	59.7	"	" "
Roadway, center panels—timber.....	43.1		
girders.....	27.3		
	70.4	"	" "

Stability of Walls.

Let P = total wind force per panel.

p = pressure per square foot.

(*a*) North Wall.

Moment stability $= 21\,100 \times \frac{16.1}{12} = 28\,309$ ft.-lbs.

Moment overturning $= P \times 8.68$

For equilibrium $P = \frac{28.309}{8.68} = 3\,261$ lbs.

$p = 3\,261 \times \frac{1}{56} = 58.2$ lbs. per square foot.

(*b*) South Wall.

Moment stability $= 37\,000 \times \frac{11.65}{12} = 35\,921$ ft.-lbs.

Moment overturning $= P \times 8.66$

$P = \frac{35\,921}{8.66} = 4\,148$ lbs.

$p = 4\,148 \times \frac{1}{92.6} = 44.8$ lbs. per square foot.

Wall and Floor Overturned Together.

The equations will assume their simplest forms if all forces are replaced by their equivalents acting on the line of the top of the walls.

This will involve:

First.—Computing the stability of each wall due to its own weight and the weight of the floor resting upon it, and finding the equivalent horizontal reaction at the top of the wall.

Second.—Computing the total wind forces acting on all exposed surfaces, and finding an equivalent force concentrated on the line of the top of the wall.

Equating these quantities will give the result sought.

As the area of the south wall can be acted on by only a part of the wind which passes through the openings in the north wall, the effective pressure must be reduced by an appreciable but uncertain quantity. The coefficient of reduction of 0.8, commonly used in computing the wind pressure on leeward trusses of bridges, has been used in this case. As the actual shelter is probably more than that, the use of this coefficient will underestimate the pressure and give a final result too small.

The values for center and end panels are separately computed, since the dead load of the girders resting on the wall is different in the two cases.

Let p = pressure of the wind per square foot.

P = equivalent force of total wind pressure acting at top of wall.

F_n = reaction at top of north wall equivalent to its total resistance.

F_s = reaction at top of south wall equivalent to its total resistance.

$F = F_n + F_s$.

Computations for Center Panel.

Stability of the Walls.

(*a*) North wall. Weight of wall, $21\,100 \times \frac{16.1}{12} = 28\,309$ ft.-lbs.

" floor, $12\,200 \times \frac{14.5}{12} = 14\,741$ "

43 050

$$F_n = 43\,050 \times \frac{1}{13.5} = 3\,188 \text{ lbs.}$$

(*b*) South wall. Weight of wall, $37\,000 \times \frac{11.65}{12} = 35\,921$ ft.-lbs.

" floor, $12\,200 \times \frac{14.5}{12} = 14\,741$ "

$50\,662$ "

$$F_s = 50\,662 \times \frac{1}{17.75} = 2\,854 \text{ lbs}$$

$$F = F_n + F_s = 3\,188 + 2\,854 = 6\,042 \quad \ldots\ldots(1)$$

Force of the Wind.

Against north wall, $56.0 \times \frac{8.68}{13.5} \times p = 36.0\,p$

" south " $92.6 \times \frac{8.66}{17.75} \times p \times \frac{8}{10} = 36.1\,p$

" floor 21.5 $\times p = 21.5\,p$

$93.6\,p$

$$P = 93.1\,p \quad \ldots\ldots(2)$$

For equilibrium (1) = (2); $6\,042 = 93.6\,p$

$p = 64.5$ lbs. per square foot.

End Panels.

For the end panels the only difference lies in the weight of the floor resting on walls, which is 5 600 lbs. in place of 12 200 lbs. per panel. Making this change, the above equations will give the value $p = 53.5$ lbs. per square foot.

If the decking be assumed to act as a horizontal girder distributing the forces uniformly, then the average for the fourteen end and seven center panels becomes 57.2 lbs. per square foot.

The amount of material actually moved by the wind was 580 tons of masonry and 280 tons of flooring and girders, a total of 860 tons.

The preceding values, 58.2 lbs. per square foot, on the north wall acting alone, or from 53.5 lbs. to 64.5 lbs. per square foot for the entire structure acting as a unit, are the static pressures which, if exerted, will just put the material on a balance if it were standing alone. Considering that some additional concentration of force was necessary at each end to tear the material loose from the rest of the structure, and also some additional force was necessary to overcome the inertia of the total mass and set it in motion, it is fair to assume that the total pressure exerted must have been at least 60 lbs. per square foot.

The masonry of the north wall fell over on the tracks. Four of the heavy girders and some planking remained on the track floor. The masonry of the south wall and most of the iron work was lying on the ground within 75 ft. of the structure. The timber of the floor was scattered along the river front for a distance of 400 ft. The construction of the floor would naturally cause it to hold together in sections of about 17 x 18 ft. that would float on the wind some distance and carry the girders with them till the fastenings broke. One of the heavy girders was carried a distance of 120 ft. from its original position, and a section of the iron handrailing was found about 1 300 ft. from the bridge.

In addition to the damage to the east arcade, a section of the timber floor 150 ft. long on the center span of the bridge was torn up and carried away by the wind. The construction was the same as for the floor over the arcade.

These facts and figures show that at the center of the bridge for a length of 150 ft. the wind must have exerted a lifting pressure of over 59 lbs. per square foot; that at the east end of the bridge the wind must have exerted a force equivalent to a uniform static pressure of at least 60 lbs. per square foot over an area at least 180 ft. long by 18 ft. high.

It is more probable, however, that the area of destructive pressure was more than 18 ft. high, and that the pressure was not uniform, but a maximum near the center and less at the sides. The disturbance of the adjacent bridge floor and destruction at the east tower would indicate a width of about 300 ft. for this area of extreme pressure.

Brick Chimney.—The power plant of the Union Depot Electric Railway Company is located near the southwestern part of the area of maximum destruction shown on the map, Fig. 1. The effects of the storm at this place are indicative both of the extreme intensity of the wind pressure and of the sharp variations in this intensity in short distances.

Fig. 1, Plate IV, is engraved from a photograph looking northeast over the carsheds toward the chimney.

The chimney fell over toward the north on the engine and dynamo-house, cutting it into two sections. The part toward the east was blown down and totally wrecked by the wind; the section on the west was almost entirely uninjured. The boiler-house was unroofed and its walls partly destroyed; the carsheds were completely wrecked,

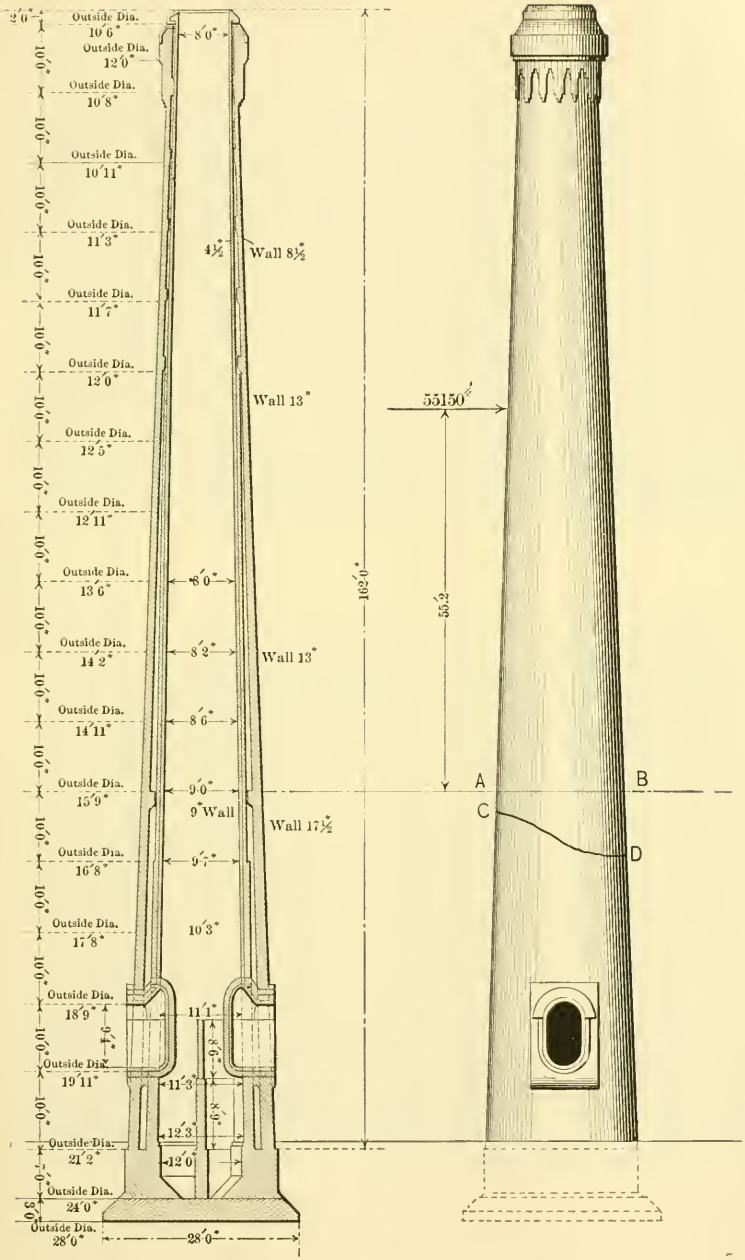
2′0″
Outside Dia. 10′6″
Outside Dia. 12′0″
Outside Dia. 10′8″
Outside Dia. 10′11″
Outside Dia. 11′3″
Outside Dia. 11′7″
Outside Dia. 12′0″
Outside Dia. 12′5″
Outside Dia. 12′11″
Outside Dia. 13′6″
Outside Dia. 14′2″
Outside Dia. 14′11″
Outside Dia. 15′9″
Outside Dia. 16′8″
Outside Dia. 17′8″
Outside Dia. 18′9″
Outside Dia. 19′11″
Outside Dia. 21′2″
Outside Dia. 24′0″
Outside Dia. 28′0″
8′0″
4½″ Wall 8½″
Wall 13″
8′0″
8′2″ Wall 13″
8′6″
9′0″
9″Wall
Wall 17½″
9′7″
10′3″
11′1″
9′8″
11′3″
6′8″
12′3″
12′0″
28′0″
162′0″
55150′
55.2
A
B
C
D

FIG. 8.

while the machine-shop was but slightly damaged. All these buildings were of the usual type of construction employed for such purposes, consisting merely of side walls and roof carried on posts or trusses. But a small part of the pressure exerted to overturn the chimney would have completely demolished every one of the buildings. The construction of the chimney is shown with details and dimensions in Fig. 8. It consisted of an outer shell built of selected, hard-burned dark red brick laid in a mortar of equal proportions of one part Portland cement to two parts sand, and one part lime to two parts sand. The bricks were laid with push-joints under inspection, and all joints were well filled.

The inner core was built of a ring of 4½-in. fireclay brick, reinforced in the lower section by a ring of hard-burned red brick. The firebrick were laid in fireclay. Each shell was finished at the top by a cast-iron cap 2 ft. deep, of ½-in. metal, secured to the brickwork by bolts. The inner shell was separated from the outer by a varying distance; the dimensions on the drawing give this distance as a minimum of 2 ins. at the top, and the same 50 ft. below the top where the section changes. This annular space would probably vary somewhat in actual construction. The inner shell was stayed by brackets built into the outer shell at intervals of 10 ft. There were six of these brackets on a level, each having a face of about 8 x 8 ins.

The upper section of this chimney, about 110 ft. high, was overturned by the wind. The portion left standing varied from 40 to 47 ft. in height, as shown by the line *C D*. With the exception of several vertical cracks it was in such good condition that after taking down about 5 ft. of the brickwork, the chimney was rebuilt on the remaining section. The cast-iron shells forming the caps of the chimney were shattered by the fall, and the fragments lay in different places; they were probably blown about by the wind. Some of the largest sections were found in a cellar just inside the line of the building and 100 ft. from the chimney. Most of the débris fell in the engine-room between the base of the chimney and the street, and part of it to the south of the chimney. The lightning-rod was thrown forward across the street. Almost immediately after the fall of the chimney, the wind veered around and blew in the opposite direction.

The change in section from 17½ ins. to 13 ins. thickness at level *A B* makes this a point of comparative weakness. This, taken in con-

FIG. 1.

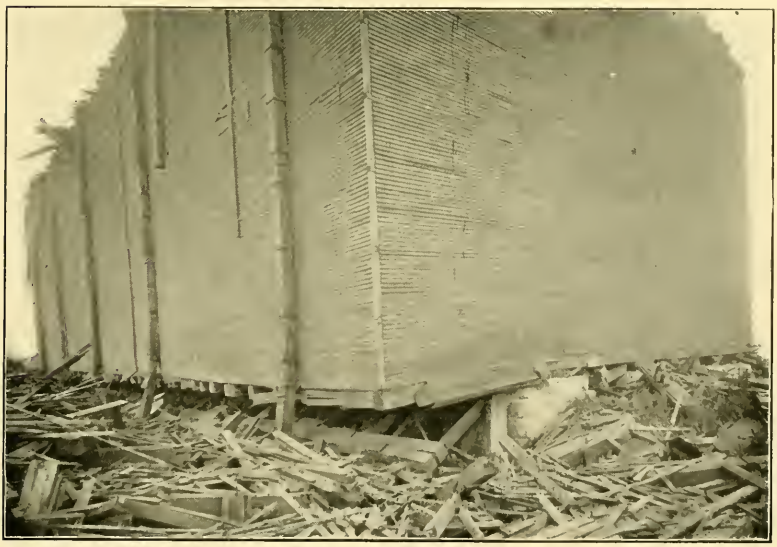

FIG. 2.

nection with all other facts, renders it probable that the chimney failed by the crushing of the brick masonry on the extreme leeward side just above the section *A B*, due to the concentration of pressure at that point, and overturned bodily; that the rupture of the walls shattered the brickwork for some distance, and that the shifting wind blew off the loose fragments down to the line *C D* and scattered the débris about the base.

Stability of Chimney.

The following computations have been made, as closely as possible in accord with actual conditions, to find the least force which must have been exerted by the wind to cause the failure of the chimney at the section *A B*. The assumptions made for this purpose are:

I.—That the joints can take no tension and that when the center of pressure has reached its limiting position, the joints have opened from the windward side diagonally across the base of the chimney, leaving a wedge above the line *A B*, which does not take part in the movement of the upper section.

II.—That the mortar has sufficient coherence to hold the upper section in shape till it has passed the point of equilibrium.

III.—That the weight of red brick masonry is 115 lbs. per cubic foot, and the weight of firebrick 120 lbs. per cubic foot.

IV.—That the brickwork will not fail by crushing till the pressure has reached a value of 50 to 70 tons per square foot, or about 700 to 1 000 per square inch. A wide range in value assumed for the crushing strength has little effect on the final result in this case, as will be seen hereafter.

V.—That the effective air pressure on a cylinder is 0.54 as much as on a plane surface whose area is equal to that of the diametral section of the cylinder. The valuation of this coefficient is the most uncertain element in the problem. It is variously given from 0.5 to 0.6, a range of nearly 20 per cent. In designing new work it is sufficient to assume a safe value, but in the present instance it is essential to have as nearly the true value of this coefficient as possible. The value of 0.54 has been taken as representing nearly a mean between the latest values determined experimentally by entirely different methods. Professor Kernot by experimenting with models placed on a delicate movable carriage in front of an air blast has found this value to be

0.52, while the experiments of Irminger made with hollow models placed in an air duct, by means of which the actual pressure at all points on the surface of the cylinder was determined, give the value of this coefficient as 0.57.

Computation for Outer Shell.

Let p = pressure of wind per square foot.

F = total force of the wind against the section overturned.

Y = distance of center gravity of exposed surface above $A\ B$ = 55.2 ft.

W = total weight of section of chimney overturned.

x = lever arm of weight W = distance from center of gravity of W to center of pressure.

Overturning Force of the Wind.

Total area of diametral plane above $A\ B$	1 386 sq. ft.
Average area of wedge at base	93 " "
Net area	1 293 " "

Effective area = 1 293 sq. ft. $\times$ 0.54 = 698 sq. ft.

then $F = 698\ p$.

Moment overturning = $y\ F = 55.2\ F$ ..... (1)

Resistance of Chimney.

Total brickwork above $A\ B$ = 3 871 cu. ft. at 115 lbs. =	445 165 lbs.
Deduct wedge at base 187 cu. ft. at 115 lbs. =	21 505 "
Net weight of brickwork	423 660 lbs.
Cast-iron cap and fastenings	3 340 "
Total weight overturned = W	427 000 "

Distance center of chimney to center of gravity of wedge at base = 4 ft.

Distance center of chimney to center of gravity of $W = \frac{21\ 505}{427\ 000} \times 4.0 = 0.2$ ft.

Assuming center of pressure to fall at center of outer shell, or $6\frac{1}{2}$ ins. back from face of chimney, gives 7.33 ft. from center of chimney to center of pressure.

Then $x = 7.33$ ft. $- 0.2$ ft. $= 7.13$ ft.

Moment resistance $= Wx = 427\,000 \times 7.13 = 3\,044\,500$ ft.-lbs. (2)

For equilibrium (1) = (2) $55.2\ F = 3\,044\,500.$

$$F = 55\,150 \text{ lbs.}$$

$$p = \frac{F}{698} = 79.0 \text{ lbs. per square foot.}$$

The deduction of the wedge at the base makes a difference of 6 lbs. in the result; that is, if the entire chimney above $A\ B$ is assumed to hold together and resist overturning, the value of p becomes 85 lbs. per square foot.

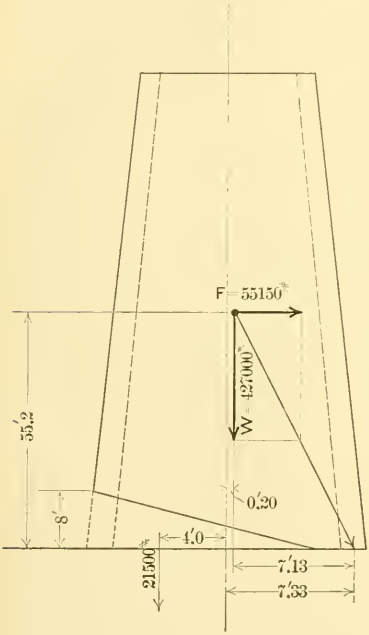

Fig. 9.

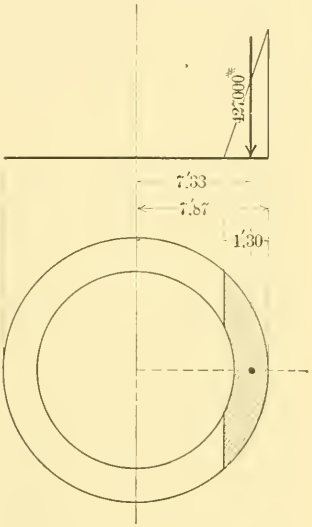

Fig. 10.

Making the customary assumption that the pressure is distributed at a uniformly varying rate, it can be graphically represented, as in Fig. 10, by a hollow wedge, the volume of which is equal to the weight W, and the base and altitude such that the center of gravity of the wedge must coincide with the position assumed for the center of pressure of the load W, in this case $6\frac{1}{2}$ ins. from the edge of the wall.

The direct mathematical formulas for the hollow wedge are quite intricate and difficult of application, particularly for small segments.

The values given here were found by successive trials. By drawing the plan on a large scale, assuming the width of the base of the wedge, and dividing the latter into small vertical prisms, the volume and center of gravity, in terms of the pressure on the extreme edge, can be readily found by use of a slide rule, with an error of less than 1 per cent. Varying the base by successive increments, a few trials will not only give the desired results, but also show more clearly than the formulas the change in these results due to changing the assumed data. For the center of pressure assumed, 6½ ins., from the face of the wall, the wedge was found to have a base 1.3 ft. wide, and an area of 7.15 sq. ft., and the pressure on the extreme edge was found to be 2.33 times the average pressure, or $2.33 \times \frac{213.5}{7.15} = 69.5$ tons per square foot.

A small variation in the position of the center of pressure will make a great difference in the theoretical pressure on the extreme edge. If it be moved toward the center 0.1 ft., the maximum pressure becomes 53.9 tons per square foot; and if moved toward the edge of the wall 0.08 ft., the maximum pressure becomes 87.8 tons per square foot. A total variation, therefore, of only 0.18 ft. in the position of the center of pressure, and consequently of the length of the lever arm, making a difference of only 2½% in the computed wind force. will change the maximum pressure on the extreme edge of the brickwork from 53.9 tons to 87.8 tons per square foot, a variation of 62 per cent. The limit assumed in this particular case for the crushing resistance of the brickwork can therefore have but little effect on the final estimated wind pressure. It is moreover improbable that the pressure will vary from 69 tons to zero in the short distance of 1.3 ft. For such an extreme weight on a small area a slight compression of the mortar will quickly redistribute the pressure more uniformly, giving a much lower unit pressure than found by the formula.

The total weight of the inner shell or core above the line $A\ B$ is 107½ tons. A computation similar to the preceding one shows that this weight will be held in equilibrium by an external force of 17 600 lbs. applied 56.1 ft. above $A\ B$. This is equivalent to a uniform pressure of 24.8 lbs. per square foot over the effective surface exposed to the wind.

The value to be placed on the core in estimating the ultimate strength of the entire chimney is uncertain. Although in the design

of a new chimney entire dependence should be placed on the outer shell, it is evident that the latter cannot be actually overturned unless the core is taken with it. The extent to which the possible resistance of the core will be effective at the moment when the outer shell is brought to the point of failure will depend upon the efficiency of the brackets, the distance between the shells at the top, and the relative stiffness of each shell.

The deflection of a brick chimney under extreme lateral forces cannot be definitely computed. It will depend upon the elasticity of brick and mortar under compression on the leeward side, and upon the opening in the joints on the windward side. As any movement in the joints near the line *A B* will cause a lateral motion of seven times that amount at the top, it is quite probable that the outer shell will be brought to a bearing against the core in case the brackets do not prove efficient. From such approximate computation of the stiffness of the shells as the case will admit, the author assumes that at least one-fourth to one-half of the possible resistance of the core must be taken into account, or a pressure of from 6 lbs. to 12 lbs. per square foot must be added to the resistance of the outer shell. This gives a total of 85 lbs. to 91 lbs. per square foot necessary to hold the chimney just at the point of equilibrium. To this must be added some additional pressure to overcome the inertia of the mass and set it in motion.

The preceding data and computations show that the wind must have exerted in this locality a force equivalent to a static pressure in excess of 85 to 91 lbs. per square foot over an area at least 14 ft. wide by 110 ft. high. The total material moved was 321 tons.

It is probable that the pressure was not uniform, but greater near the top. It is also possible that the chimney was overturned either by successive gusts of wind whose period of recurrence was timed to the oscillations of the chimney or by one sudden and intense blast. In the former case the actual pressure of the wind might be much less, in the latter it would be more than that given by the above figures.

The Valley Grain Elevator.—The largest and heaviest single object that was moved by the wind is a grain elevator standing on the east shore of the Mississippi River on about the south line of the path of the storm. This building is of the usual type of elevator construction and is shown in outline and general dimensions in Fig. 11. The heavy

lines indicate the present position of the wreck as seen in Fig. 2, Plate IV, and Fig. 1, Plate V; the light lines indicate its position before the storm. The upper part of the building or cupola was about 50 ft. wide by 58 ft. high, and extended the full length of the building. It consisted of a framework of timbers supporting a series of partial floors on which were located the machinery, bins, scales, distributing chutes, etc., which constitute the operating mechanism of a grain

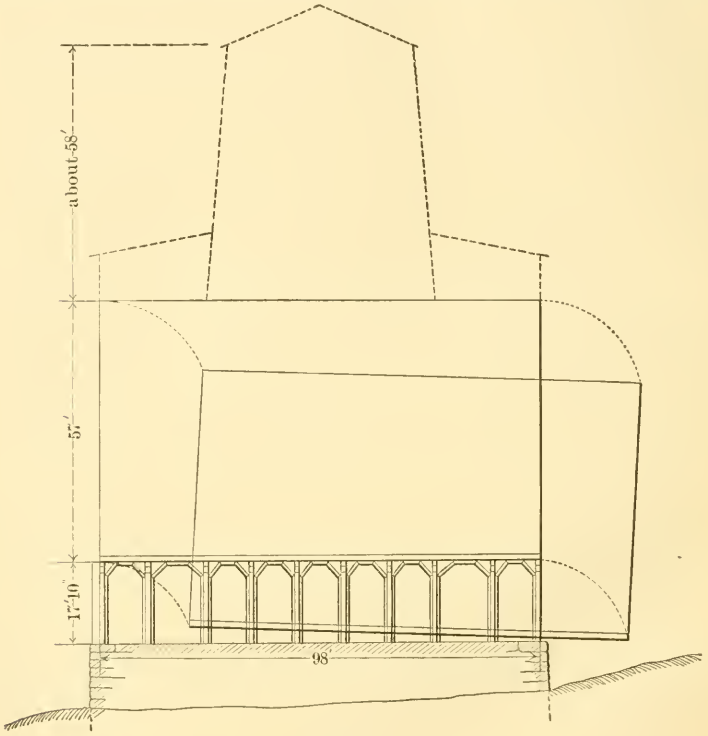

FIG. 11.

elevator. The binwork or lower section of the building proper is 57 ft. high, 98 ft. wide, and about 200 ft. long. It is divided into bins about 11 ft. square by a series of ten longitudinal and nineteen cross-walls built up of 10-in., 8-in. and 6-in. planks, laid flat on each other and securely spiked together. These walls form in effect a series of deep wooden girders intersecting and interlocking into each other and forming a huge box of great strength and rigidity. Im-

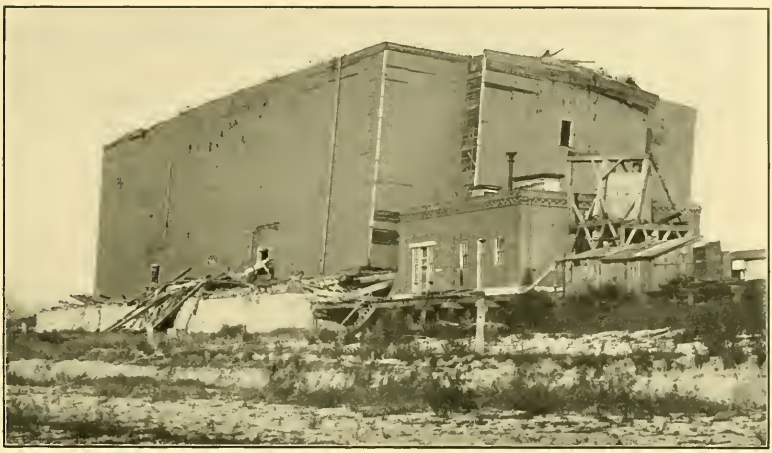

FIG. 1.

FIG. 2.

mediately underneath each outer and cross-wall is a 12 × 16-in. timber sill, which is fastened to and forms a part of the wall above it. The sills and the entire structure are carried by the "twin girders," a series of double timbers, a 12 × 14-in. placed on top of a 14 × 14-in., running under each longitudinal wall and supported in turn by 12 × 14-in. vertical posts, one under each point of intersection of these main timbers. The posts rest on a substantial foundation of stone walls and piers. The details of posts and bracing are shown in

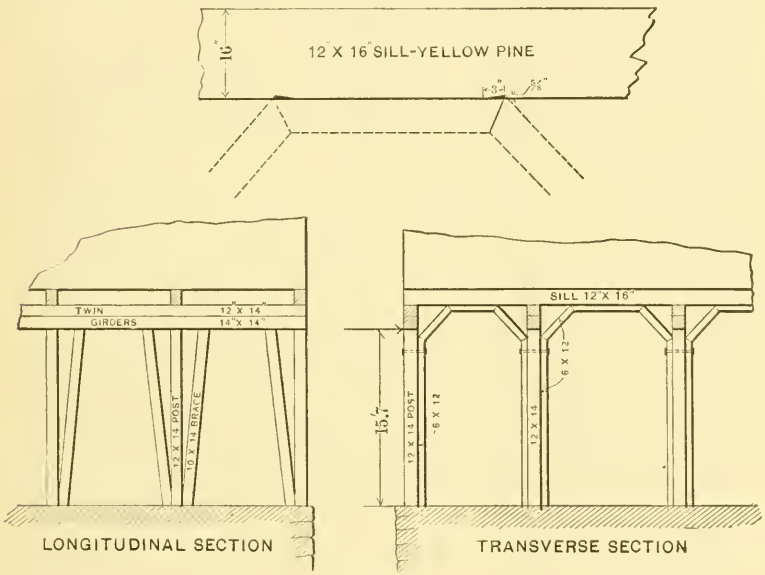

FIG. 12.

Fig. 12. The posts are reinforced by 6 × 12-in. side and diagonal pieces shown in the cross-section, which act partly as braces for lateral stiffness and partly as additional supports to the sills when the bins are fully loaded. Batter posts are used as bracing in the longitudinal direction.

The wind blowing from the west pushed over the entire structure with its supports and tore off and overturned the framing and contents of the cupola down to the level of the bin floor. The building was moved towards the east 19½ ft. at the south end, and 18½ at the north end, and towards the north about 1 ft. As the distance from the

bottom of the posts to the sill was 17 ft. 10 ins., the building moved sideways but little more than the distance it fell, the path of motion probably being on nearly the arc of a circle, having the height of support as its radius. The binwork, somewhat racked and out of plumb, is resting on the foundation and overhangs the east wall, as shown in Fig. 2, Plate IV, from a photograph taken from the northeast corner; Fig. 1, Plate V, is a view taken from the southwest. The face of the building was originally above the stone foundation wall and nearly on line with it. The timbers showing above the wall at the left-hand end of the plate formed the outer row of supports.

This elevator was built in 1883, and no records showing details of construction were accessible. The dimensions of the binwork and supports were obtained by measurements taken from the wreck; the cupola was assumed to be the same as that on other elevators of similar construction and dimensions. The building was empty at the time of the storm. The estimated dead weight of the structure is about 3 500 tons, with a possible error of several hundred tons either way.

The uncertainty as to the exact height of the cupola, and the exact weight of the total building, and particularly the indeterminate value of the bracing, renders a definite estimate of the wind pressure impossible. The bearings of the sills on the longitudinal girders, and of the latter on the posts, were unsecured in any way except by the friction due to the weight. The 6 x 12-in. uprights were fastened to the post by a single bolt, and the diagonal pieces were toe-nailed to hold them in place.

The maximum resistance due to the weight alone will be brought into action after some movement, causing some inclination of the posts, has taken place and has thrown the bearing to the leeward edge at the base and towards the windward edge at the top of the post, giving an effective lever arm of possibly 10 ins. Then

$$\text{Moment of resistance} = 7\,000\,000 \times \frac{10}{12} = 5\,833\,000 \text{ ft.-lbs.}$$

$$\text{“ “ overturning} = F \times 15.7.$$

$$\text{Total wind force} = F = \frac{5\,833\,000}{15.7} = 371\,500 \text{ lbs.}$$

$$\text{Exposed area} = 115 \text{ x } 200 = 23\,000 \text{ sq. ft.}$$

$$\text{Pressure per square foot} = \frac{371\,600}{23\,000} = 16.1 \text{ lbs.}$$

The evidence of the resistance offered by the bracing is seen in the crushing of the fibers of the yellow pine sills. The diagonal pieces crowding against each edge of the upper horizontal timbers have in many instances crushed the latter into the underside of the girders, leaving an indentation triangular in shape, $\frac{5}{8}$ in. deep as a maximum, as shown in Fig. 12. The exact value of this resistance is indeterminate, but it would materially increase the wind pressure necessary to move the building, making it probably 20 lbs. or more to the square foot.

It would seem reasonable to conclude that in this case the wind must have exerted a force equivalent to a static pressure at least 16 lbs. to 20 lbs. or more per square foot over an area at least 200 ft. long by 115 ft. high. It is probable, however, that the pressure was not uniform, but was double this amount or more against the upper part of the building. The slight movement of the building toward the north, and the greater lateral displacement at the south end would indicate a diagonal direction of the wind and a heavier pressure near the latter end, while the fact that the brick building used as an engine-room standing at the south end was entirely uninjured by the wind would indicate that the pressure was varying and greatest near the top.

The grain elevators located along the river front have all suffered more or less, owing to their height and exposed condition. In four other buildings the cupolas were overturned and completely wrecked. One of these buildings showed indications of racking, though partially loaded with grain at the time. In another elevator, a building 350 ft. long and of the same general construction as that described, except that it was braced more effectively with the batter posts in the transverse section, there were evidences that the building had been partially moved out of place and settled back again. The plumb posts on the extreme leeward side were moved outward at the bottom for half the length of the building, the displacement being 11 ins. at about the quarter point and varying to nothing at the middle and end of the building. On the windward side many of the batter posts had fallen out of place and were found on the floor. Several sections of the cupola at the end were torn away. The great length and stiffness of this building probably prevented it being pushed over on its supports. The equivalent pressure was at least 20 lbs. for a length of 100 ft. of building. This elevator is parallel to and north of the bridge, and the wind was from the north or the same direction as at the bridge.

Mercantile Buildings.—The damage wrought on some of the large and substantially constructed buildings, of which there were only a few in the path of the storm, will convey some further impression of the force of the wind, even if it cannot be definitely estimated.

A building of this type is represented in Fig. 2, Plate V. It is 64 ft. wide by 126 ft. long and six stories high, built with heavy exterior walls and with standard mill construction on the interior. The full wall shown in the illustration faces west; the east face is similar in construction to the south front. The brickwork in the top story was 13 ins. thick in the full wall, 17 ins. in the pilasters between the windows, and was all laid in mortar of lime and Louisville cement. It was built three years ago, so that the mortar had ample time to set. The roof was constructed of a double thickness of planking with an air space filled with mineral wool, and was furnished with an extra heavy tar and gravel covering. It was carried on beams supported by 9 x 9-in. uprights, and would probably weigh about 20 to 25 lbs. per square foot.

The entire sixth-floor walls were demolished and the roof lifted and carried off by the wind, part of it falling on and crushing the one-story building immediately adjoining it on the west. The wind evidently blew into the east windows and lifted the roof, as nearly all the posts, with the cast bearing-plates still on top of them, were left standing in place; the first row can be seen in the illustration.

A second example of the damage done to a substantial building is given in Fig. 1, Plate VI, which shows the south wall of the upper four stories blown out by the difference in pressure of the air on the inside and the outside of the building, the material of the walls all falling on the outside. The walls were 13 ins. thick in the fifth and sixth stories, and 18 ins. in the third and fourth stories; the pilasters which supported the floor girders were 26 ins. thick. The building was erected about eight years ago. With the exception of the parapet wall and a section of the upper story of the building, it sustained no other serious damage.

Another instance of a brick wall blown out by a difference in pressure occurred in the elevator building at one of the large brewery plants, a brick shell, constructed around the grain bins, having its walls stayed at intervals by slip anchors fastened to the sides of the wooden bins. The end wall, 13 ins. thick, 40 ft. wide, and about 75 ft.

FIG. 1.

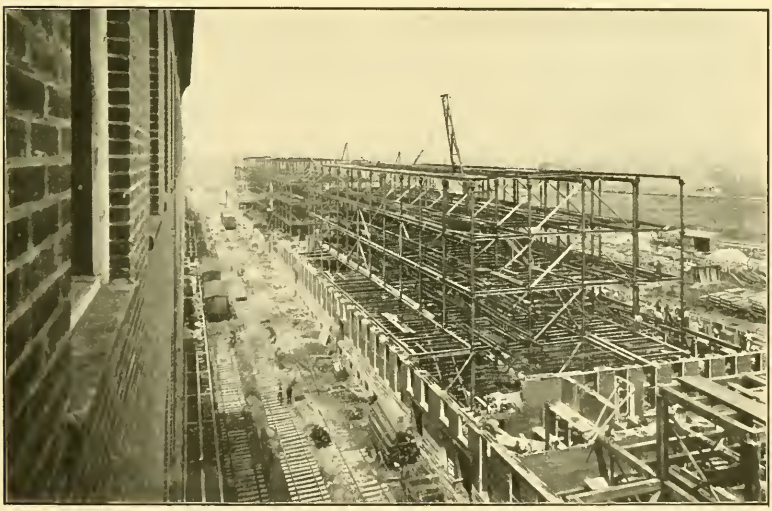

FIG. 2.

high, was forced out its entire height. The brickwork in this case was laid in Portland cement mortar, and was of excellent quality. The débris showed large sections of brick masonry still bonded solidly together, the wall evidently breaking through the bricks as readily as at the joint.

In Fig. 2, Plate VI, is shown the framework of a group of three mercantile buildings in various stages of construction, about as they appeared on the day of the storm, the view being taken sometime previous. The buildings are four stories and basement in height, about 110 ft. wide by 250 ft. long, situated end to end in one line, and partly separated by open courts. The outer walls are of heavy brick masonry; the interior consists of a skeleton framework of cast-iron columns and steel beams. The metal-work was completed, except the beams of the outer panels of the upper floors, which were necessarily omitted until the walls were brought up to the proper height. The framework of the building in the foreground, some 1 200 to 1 500 tons in weight, was completely wrecked by the storm, the view in Fig. 1, Plate VII, showing the result. The building at the extreme end had the upper two or three stories wrecked, while the frame in the center building escaped uninjured.

The floor plan of the building was of the customary design, the essential features being shown in Fig. 13. It consisted of longitudinal girders of two 15-in. I-beams fastened together with the usual cast separators. The trimming joists were 15-in. I-beams, and the floor beams were 12-in. I-beams, coped and framed into the girders so as to be flush on top. In the outer panels a 15-in. I-tail trimmer, adjacent to the wall and framed into the 15-in. trimming joists opposite the column connections, carried the headers, which otherwise would have rested directly over the windows, in the brick walls. All connections were made with standard 6 x 6 x $\frac{7}{16}$-in. connecting angles, with five holes in each leg, which came shop-riveted to the end of the 12-in. floor beams. The field connections to the girders at all interior points were necessarily made with long bolts; all connections in the outer panels adjacent to the wall were riveted, bolts and rivets being $\frac{3}{4}$ in. diameter. The cast columns were fastened to each other by four $\frac{3}{4}$-in. bolts through heavy flange lugs at each joint, the girders and beams being supported on brackets and bolted through their webs to vertical lugs cast on the columns.

The details of the wreckage, representing, as they do, a drop test of full-size members on an unusually large scale, present some points of interest in regard to the behavior of the material under extreme conditions that have a direct application to some details of customary practice in the steel framework of high buildings, and are therefore given at some length.

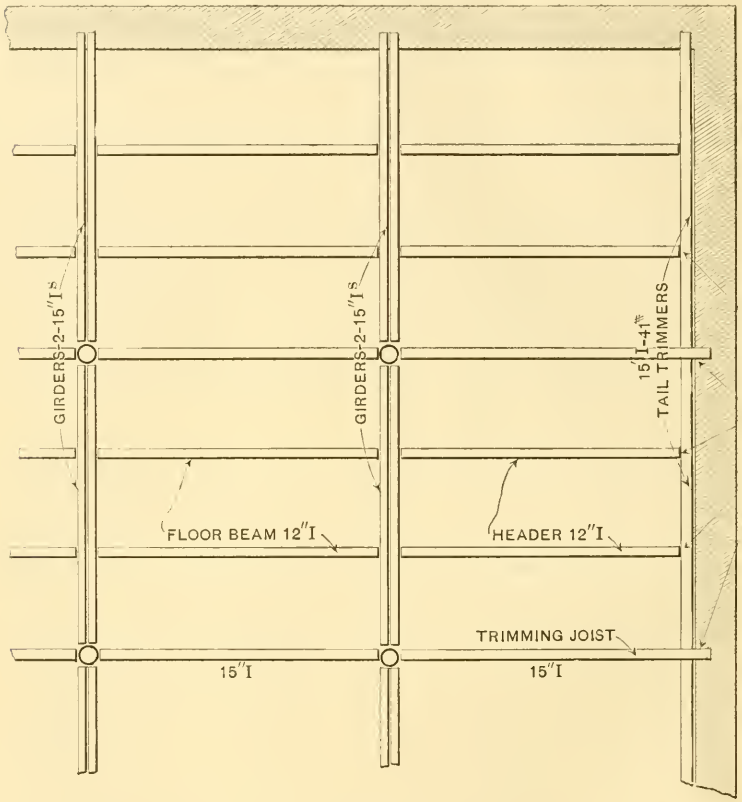

Fig. 13.

The roof beams and girders which fell on top of the wreck were subjected to no shock except that due to their own weight, and were nearly all in good condition. The floor beams on the various floors, being caught between falling columns and girders, were badly bent and twisted. The author was informed that a number of the beams had the flanges cracked, and he personally saw several beams broken off

FIG. 1.

FIG. 2.

at the ends, the fracture beginning at the end of the coped top flange and extending diagonally across the web and bottom flange, as shown in Fig. 14. A common method of failure is shown in Fig. 15; the flange of the beam, probably due to a blow coming on one edge, is doubled almost into the line of the web, and both are deflected sideways. A careful inspection of numerous cases of extreme distortion similar to the last failed to show any cracks in the metal.

A striking fact noted throughout the work of clearing the wreck was the superiority of riveted over bolted connections when the joints are subjected to strains from bending, twisting or wrenching, such as they might be called on to resist in the column connections of a high building. In most of the roof beam connections, and in some of the joints in the floor where the beams maintained their relative position, the bolts were good, but wherever the beams were twisted out of

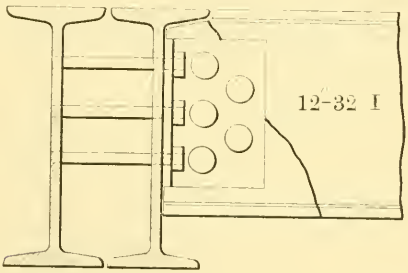

FIG. 14.

FIG. 15.

position, the bolts invariably failed. Fully two-thirds to three-fourths of all the bolted connections were either broken apart or so weakened that the beams could be easily pulled apart. The riveted joints, on the other hand, made a much better showing. The floor beams of the outside panels of the first and second floors were nearly all in place, and the joints riveted at the time of the storm. These beams were caught beneath the falling material of the upper floors and were dragged down against the side wall in such a way as to twist most of the beams and girders out of line and position. Although these joints were thus subjected to the severest test of any in the structure, yet in nearly every instance they hung together and required the rivets to be cut out before the wreckage could be cleared. The line of tail trimmers of the second floor can be clearly seen against the wall shown in the right-hand side of Fig. 1, Plate VII, which is a view of the wreck

taken shortly after the accident. Fig. 2, Plate VII, is a view taken during the clearing of the wreck.

At various times during the clearing of the wreck the author made a detailed examination of 49 of these joints, containing a total of 735 rivets. As on an average, at least three rivets out of the fifteen at each joint were strained in tension, there were 149 rivets in this number that were put to a severe test. Fifteen of these rivets, or about 10% of the number, were found with the heads off or broken in the body, and seven were noticed that had been elongated on one side as much as $\frac{3}{16}$ to $\frac{1}{4}$ in. The maximum number that failed at any one joint was three, and in every instance the rivets that were broken or excessively distorted were in the inner row. In three places the material had been so violently wrenched that both connecting angles were torn apart at the root of the angle, and the beams pulled entirely away from each other, and in two other instances one of the angles was torn apart; otherwise the girders hung together by the riveted joints in continuous sections. In no instance was a connecting angle torn entirely off from any beam to which it was riveted.

Plate VIII shows some of the distorted rivets, a broken bolt, which is a characteristic specimen, and half of one of the connecting angles that was torn apart. The last was still attached to the web of the beam by the three rivets, about in the position shown in the illustration. The rivets were still sound and were cut out in clearing the wreck. Evidently the angle, when pulled away from the beam, split at the rivet holes and pulled over the rivet heads, which were somewhat eccentric and did not have their full grip, acting much like soft paper torn from a board to which it is nailed.

At most of the joints the beams were bent around toward the girder to various angles, in some places as small as 30 degrees. Fig. 16 is a sketch of a joint at the connection of a 12-in. header to the 15-in. tail trimmer, made from measurements taken on the center line of the 15-in. I-beam, and is characteristic of the condition of a great many of these connections.

The bottom flange of the beam, being very stiff laterally, maintained its line, but the web, which was already weakened by coping of the top flange, was split away from the bottom flange and bent sharply. The connecting angles were distorted as shown, and the web of the 15-in. I-beams 0.41 in. thick were drawn as much as $\frac{1}{2}$ in. out of line. The

rivets in these connections were all sound and had to be cut out. The rivet holes in the distorted webs of the beams generally showed cracks at the edges on the convex side.

It is of course impossible to deduce any quantitative results from a test of material made under such conditions, but the number of pieces, the diversity of conditions and the general uniformity of results furnish some definite average values as to the relative strength of a few structural details when brought to the point of failure.

Considered in reference to the particular instance and type of structure in which they were observed, these facts have no application

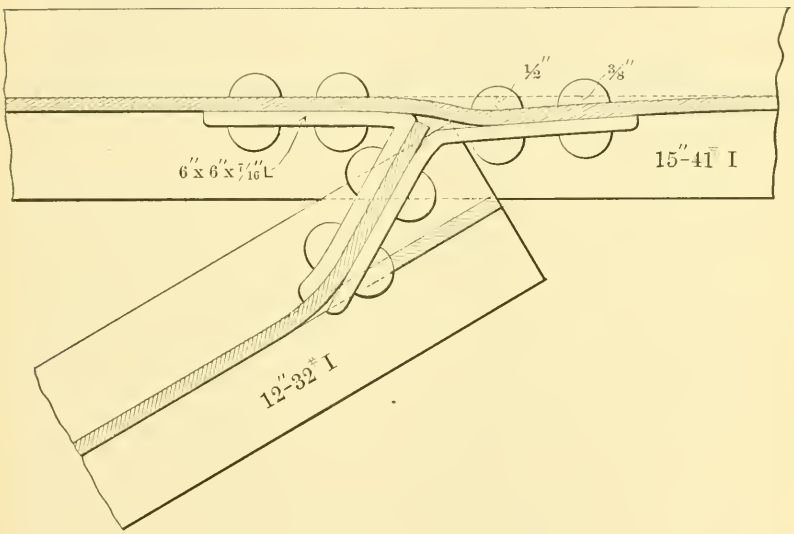

Fig. 16.

whatever. Any standard floor-beam connecting angle is probably of ample strength if subjected to only such treatment as it will receive in a floor. But as the accident subjected some of these connections to such strains as rivets, angles and bolts are often expected to resist in other places, as in the steel framing and column connections of high office buildings, some deductions have been drawn with reference to their application where they may seem appropriate.

The facts observed show conclusively:

1. That for any twisting, wrenching or bending strain a ¾-in. rivet is far superior to the ordinary ¾-in. bolt.

2. That the tension value of three $\frac{3}{4}$-in. steel rivets is sufficient to distort the web of a 15-in. 41-lb. I-beam $\frac{1}{2}$ in. out of line without failure of the rivets, and is also far in excess of the bending resistance of the metal in a $\frac{7}{16}$-in. connecting angle.

3. That a tension strain transmitted across the root of an angle from one leg to the other will cause a bending and a distortion of the angle and bring an eccentric tension strain on the nearest line of bolts or rivets, and that under such action, in an angle as light as $\frac{7}{16}$ in., the second row of rivets will not act till the first row has failed.

4. That an eccentric tension strain will readily cause a bolt to fail by bending or breaking in the thread, while the steel rivet will stand considerable distortion without failure.

5. That well-riveted joints in steelwork will stand, even under jar and shock, an excessive amount of abuse and distortion before actually separating into individual pieces.

These facts are entirely in accord with a theoretical analysis and are recorded here because they are facts, and because they apply so directly to what might be called some of the "units" of structural work.

The rivet in tension has always been an object of suspicion and distrust; it would seem consistent to be equally discriminating against some other details often used; notably the bolt in tension, the diaphragm plate resisting thrust or tension, and the thin connecting angle under cross-tension strain.

III.—Method of Action of the Wind.

While a measure of the force of the wind is of the first consideration to the engineer, the application of this force, and the more immediate influences and causes governing it, follow closely in point of interest. The volume of destruction and the many apparent vagaries of the destructive agent will justify a brief résumé of such experimental knowledge as seems to have a direct bearing on the subject, particularly as some of the results obtained from laboratory tests on models seem to find confirmation in the full-size test applied by Nature on the buildings.

Wind has been defined as "merely the flowing away of air from where there is a surplus of it to where there is a deficiency." All winds from the lightest breeze to the most disastrous hurricane take their rise in irregularities in the distribution of the atmospheric pressure,

whether these irregularities originate in the temperature or aqueous vapor. The velocity of the wind, and, consequently, the force exerted by it, must depend largely on the difference in the atmospheric pressure at any two points and the distance between them.

The relation between the flow of air and the pressure it exerts on surfaces exposed to its action is expressed by the generally accepted formula $P = c\ v^2$ were P is pressure in pounds per square foot, v is the velocity in miles per hours, and c is a constant, affected by temperature and barometric pressure, which must be determined by experiment. Notwithstanding the many careful and elaborate experiments * made to determine or verify this general formula, the value assigned to the constant c covers a wide range. The United States Weather Bureau has adopted the value $c = 0.0040$, making the formula $P = 0.004\ v^2$. A generally accepted value is 0.005, while the experiments of Whipple and Dines in England give the value 0.0029, a variation of nearly 25% either way.

As the values of this constant have nearly all been determined from velocities not over 60 to 70 miles per hour, and as it is, moreover, the general opinion of nearly all investigators that the law of pressure-velocity variations found by experiment with whirling machines is correct only within the range of speeds covered by those experiments, the values deduced from the lower velocities not being safely applicable to higher velocities, it follows that any formula must be accepted as giving only a very broad average result for velocities up to about 70 miles per hour, and only the most general approximation for velocities much higher.

Any formula expressing the relation between the pressure and velocity of the wind must be based on the assumption that the air flows in a uniform current. All experiments in the open air show that the actual conditions are far different, and the great diversity in the observed results is due largely to the continued and rapid fluctuations in the velocity of the winds. The extent to which this gusty nature is characteristic of the wind at all times and the allowance to be made for it when using the formula to convert wind velocity into pressure, appears more clearly in the detailed results of the experiments made by Professor C. F. Marvin on Mount Washington, to determine the

* See "Wind Pressures in Engineering Construction," by W. H. Bixby, *Engineering News*, March 14th, 1895.

value of the constant in the formula now in use by the United States Weather Bureau.

The pressure exerted by the wind on plates respectively 4 sq. ft. and 9 sq. ft. in area were carefully measured by a delicate self recording mechanism for velocities ranging from 7 miles to 48.5 miles per hour. The velocity of the wind was measured by the standard Robinson anemometer placed about 4 ft. higher than the center of the pressure plate and recorded by electrical contacts every fifty revolutions of the cups, equal to one-tenth of a mile of wind movement.

The following statement of results is taken verbatim from the report of Professor Marvin: *

"The records of the pressure and velocity of the wind were, therefore, automatically and simultaneously recorded on the same sheet of paper. The curve of pressures, if it can be called a curve, presents, in spite of the comparatively rapid rate of rotation of the register, a very irregular appearance indeed. The oscillations do not, except for occasional instants, correspond to harmonic vibrations of the spring and pressure plate as a vibratory system, but are actual and real changes in wind pressure. The magnitude of these variations is, itself, very irregular, but it may be stated to be approximately as much as 35% of the mean pressure. There is, in addition to these very rapid variations in the pressure which take place inside of a second or two of time, other variations which go through their irregular changes in from a few to several minutes' time.

"These circumstances led to the following method of reducing the observations. The traces on the record sheets were divided into portions representing, generally, four or five minutes of time, and during which the conditions were, to some extent, constant. The traces of the pressure were all gone over by hand and a red-ink line drawn through the pencil mark in such a manner as to get a mean curve. In this only those variations which were of such short period that the pencil marks were too close together to distinguish were evened up. All changes of larger periods were followed accurately. The next step consisted in carefully measuring the area of each subdivision, including, of course, everything between the red-ink trace and the line of zero pressure. This measurement was very satisfactorily made by a small planimeter. The mean pressure is now quite accurately found by dividing the area by the length of the base of the diagram. The mean wind velocity corresponding to the same portion of the sheet is determined from the simultaneous record of the anemometer. The large number of observations obtained in this way have been grouped in sets corresponding to the velocity, and a final mean determined.

* Annual Report, Chief Signal Officer, 1890. Report upon Wind Pressures.

"For engineering purposes this formula gives very closely, I think, the actual pressures corresponding to velocities computed by the logarithmic formula, as applied to the Robinson anemometer, and this is the instrument almost universally used in measuring wind movements. Where the Robinson anemometer, having its dials graduated to read miles, is used, the observed velocity can be easily reduced to the true velocity.*

"In estimating the strains to which engineering structures may be subjected by the winds, the maximum pressures are, of course, the most important. The above formula gives a mean pressure corresponding to a mean wind velocity. It is important to note that momentary pressures as much as 35% in excess of the above mean pressure may continually occur and recur. If their rate of occurrence be at all synchronous with a natural time of vibration of the structure or any part thereof, remarkable effects may follow."

A further and more definite evidence of the irregular and gusty action of the winds is found in the experiments of Professor S. P. Langley,† comparing the ordinary records of velocity with the actual motion of the winds. The velocities of the wind, as recorded by the United States Weather Bureau, are measured by the standard Robinson cup anemometer, which in practice is made to register only the completion of the passage of each mile of wind. As the instruments are necessarily made of a strength and weight adapted to continuous and general service, their momentum renders the motion of the cups more uniform than that of the wind. The records, therefore, give about the average velocity of each mile of wind, but do not show the intermediate variations due to sudden gusts. To determine the rate and extent of these fluctuations in velocity, Professor Langley conducted a series of experiments with a standard anemometer recording every five revolutions, and with a special anemometer made so sensitive that it would start and stop almost instantaneously with the wind. This latter instrument was made of half the usual diameter, and fitted with paper cones in place of metal cups, the weight and moment of inertia being less than 1% of that of the standard anemometer. Electrical contacts were made every half revolution, recording the velocities several times a second. Observations were taken at Allegheny City and at Washington on high points free from irregularities due to trees, houses or inequalities of the ground on different days, and in

* See table in Appendix.

† "The Internal Work of the Wind," S. P. Langley, Smithsonian Contributions to Knowledge, No. 884.

light to moderately high winds ranging in velocity from 9 to 36 miles per hour. The experiments show clearly that even the ordinary and comparatively uniform wind is but a succession of gusts of varying intensity. The results of the observations are shown graphically on a series of diagrams, one of which, selected as a characteristic example, is reproduced in Fig. 17. The diagram is an actual record for ten minutes showing the rapid changes that take place in the velocity of the wind.

The observed points represent the wind's velocities as computed from intervals between each successive contact, and for convenience are connected by straight lines.

The heavy line through *A B C* represents the ordinary record of the wind's velocity as obtained from a standard Robinson anemometer registering every mile, during the observations recording the passage of 2 miles of wind in about 5½ minutes of time. The velocity, which was nearly 23 miles per hour at the beginning, fell during the course of the first mile to 20 miles per hour and rose at the end of the second mile to 27 miles per hour.

The records of the same wind made at every second with the specially light anemometer show that, starting with 23 miles, it rose within ten seconds to a velocity of 33 miles, and within ten seconds more fell to its initial speed; it then rose within thirty seconds to a velocity of 36 miles per hour, and so on with alternate risings and fallings, at one time actually stopping—passing through eighteen notable maxima and as many notable minima, the average time of each rise or each fall being a little over ten seconds, and the average change of velocity in this time being 10 miles per hour. There were in addition almost innumerable smaller variations which the drawings cannot depict.

A prominent feature presented in the diagram is that the higher the absolute velocity of the winds, the greater the relative fluctuations which occur in it. In a high wind the air moves in a tumultuous mass, the velocity being at one moment perhaps 40 miles per hour, then diminishing to an almost instantaneous calm and then resuming.

Since the air is an elastic and nearly perfect fluid, subject to condensation and rarefaction, and its motion is practically without friction, the successive velocities of any given particle are in reality the result of incessant changes in all directions, and these continuous

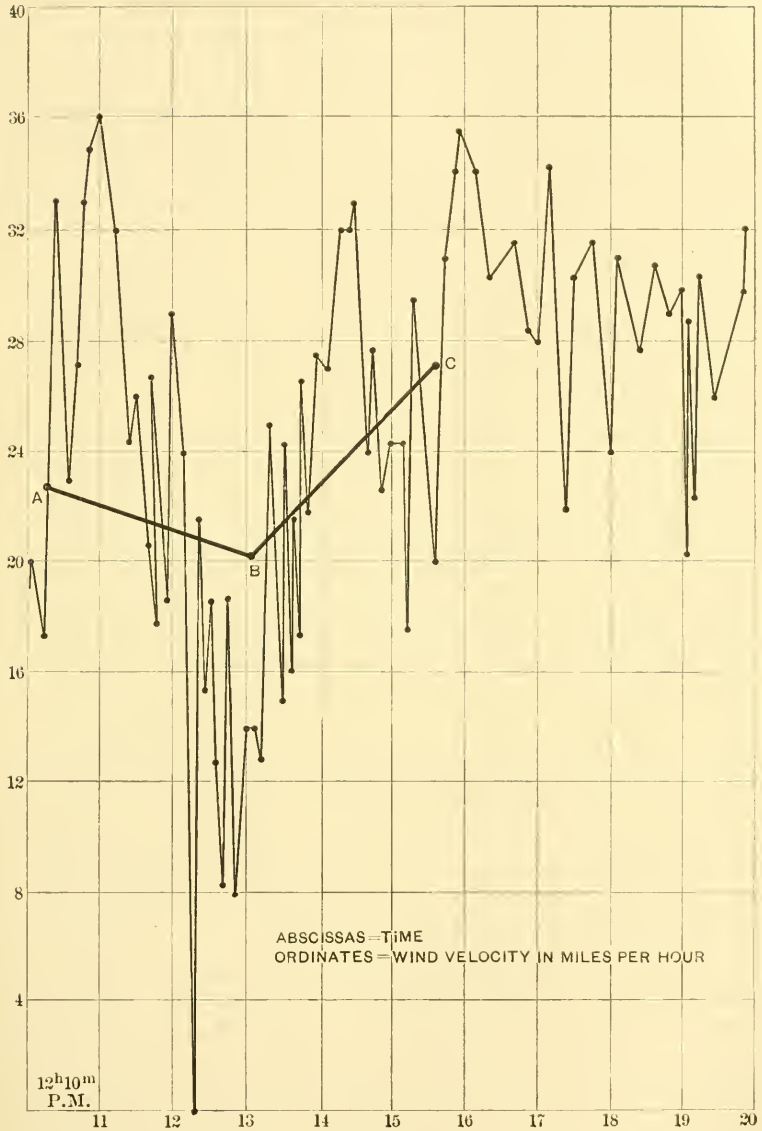
40
36
32
28
24
20
16
12
8
4
A
B
C
ABSCISSAS = TIME
ORDINATES = WIND VELOCITY IN MILES PER HOUR
12h10m
P.M.
11
12
13
14
15
16
17
18
19
20

FIG. 17.

alterations which make the wind are due to past impulses and changes which are preserved in it and die away very slowly.

Of these irregular movements of the wind which take place, up, down and on every side, only a small portion, viz., those which occur in a narrow current, whose direction is horizontal and whose width is only the diameter of the anemometer, can be noted by the instrument. However irregular the movements may appear on the diagram, they are far less so than in reality, and anything like a fairly complete graphical representation is impossible.

As a result of these observations Professor Langley reaches the conclusion that "the wind is not even an approximately uniform moving mass of air, but consists of a succession of very brief pulsations of varying amplitude, and that relatively to the mean movement of the wind, these are of varying directions."

Regarding the direct effect of wind pressure on buildings, some suggestive results were obtained by Professor Kernot* with an apparatus devised to determine the relative pressures of the wind on flat plates, cubes, cylinders and other forms similar to those employed in ordinary construction. A steady jet of air 10 x 12 ins. in cross-section was directed against small models supported on a very delicately arranged carriage running on an accurately leveled surface plate, the force exerted being measured by a delicate spring balance. From a large number of experiments made with this apparatus he found that the pressure on sloping roofs agreed with the results of theory only when the air could blow freely underneath. With the model of a roof placed on a wall, as in an ordinary building, the air was deflected upward and greatly reduced the pressure on the roof; the effect was more marked when a parapet was used. In the case of a roof of 30° pitch, with a parapet 0.16 the height of the roof, the pressure was actually reversed, the roof having a slight tendency to lift. Experiments were tried as to the effect of the wind blowing in at the open end of a building having the sides and other end completely closed, and it was found that there was an internal pressure, tending to lift the roof and force out the sides, which was equal to the pressure of the wind on the exposed end. When a plain surface, parallel to the wind, was brought nearly into contact with the cylinder, the pressure on the latter was increased nearly 20%, owing to the lateral escape of the air around the cylinder

* *Engineering Record*, February 10th, 1894.

being checked, showing that a tower or chimney will be subjected to a much greater pressure if there is a building nearly touching it on one side. The variations of pressure caused by the proximity of other surfaces were very marked; each surface appeared to affect the pressure on the other surfaces to a distance in front equal to its own breadth, and in the rear equal to several times this distance. Behind flat surfaces eddies were found to exist which caused other surfaces placed behind them to be urged forward with considerable force.

The existence of a suction on the leeward side of surfaces or bodies exposed to the wind has been generally recognized, but the experiments of Mr. Irminger,* a Danish engineer, made to determine the amount of such suctions, shows it to be present to an unexpected extent. The measurements were made by the use of hollow plates and models of thin sheet iron exposed in an air duct of $4\frac{1}{2}$ x 9 ins. cross-section, at various angles and positions, to velocities ranging from 16 to 32 miles per hour.

The bodies were supported on a hollow axis closed at one end and connected at the other with a pressure gauge, the axis communicating with the interior through a series of holes. The surfaces to be experimented with had a series of holes which were exposed in succession, one at a time, to the air current and recorded the effect of the wind, whether pressure or suction. In this way both the total effect and the percentage of it that was pressure or suction was obtained.

Although the small size of the models may give rise to some question as to the exact values obtained, the characteristic features of the experiment are so marked and seem to be so generally confirmed by the effect of the wind on buildings in St. Louis, that the results are reproduced here at some length.

It was found that with the wind blowing against the plane at small angles, say from 0° up to 5°, the total effect was due entirely to suction on the leeward side, the pressure on the windward side being zero. With the wind blowing at an angle of 10° on long and narrow planes the total effect was found to be 45% of that due to normal wind suction, and 87% of this was due to suction. With an increasing angle between the wind and the surface acted upon, the effect due to suction was reduced, but never became less than 45%; that is, the maximum percentage of pressure alone was never over 55 per cent.

* *Engineering News*, February 14th, 1895.

In the table are given the results on different-shaped prisms of the cross-section shown. p is the total pressure against the plane surface, the height of which is s; 45% of this total pressure is due to pressure on the windward side, and 55% due to suction on the leeward side. Similarly, the percentage of pressure and suction is given for different bodies, as well as the ratio the total effect bears to the total pressure on a plane surface. In the case of the cylinder, which was examined by boring a single hole in it and revolving it gradually through 360°, it was found that pressure existed only through an arc

PRESSURE IN A HORIZONTAL DIRECTION		PRESSURE ON THE WINDWARD SIDE % TOTAL PRESSURE	SUCTION ON THE LEEWARD SIDE % TOTAL PRESSURE
	p	45	55
	$0.95p$	57	43
	$0.79p$	24	76
	$0.57p$	28	72
	$0.25p$	18	82
	$0.59p$	58	42
	$0.42p$	14	86
	$0.71p$	63	37

of 70° at the front of the cylinder, the remaining four-fifths of the surface of the cylinder showing a suction action.

The most interesting result was that found for a roof sloping at an angle of 45°, as shown in Fig. 18. The pressure on the windward side was a maximum at the eaves, and became zero near the top, changing to a suction at the ridge. The effect on the leeward side was a uniform suction. Taking the normal pressure on a plane of the same dimensions as equal to p, the proportional effect on the windward side was found to be a pressure of $0.11\,p$, and on the leeward side a suction of $0.36\,p$. The resultant effect on the total roof was a force 3½

times as large as the pressure on the windward side alone, and was inclined upward, exerting a strong lifting action. In another experiment made with the model of a building covered by a dome, the resultant of the pressure and suction upon the dome was found to act vertically upward.

The results of these experiments show that the wind acts in a direction quite different from that generally assumed and usually provided for in the designing of bridges, roofs and buildings. The evidences at St. Louis confirm this conclusion.

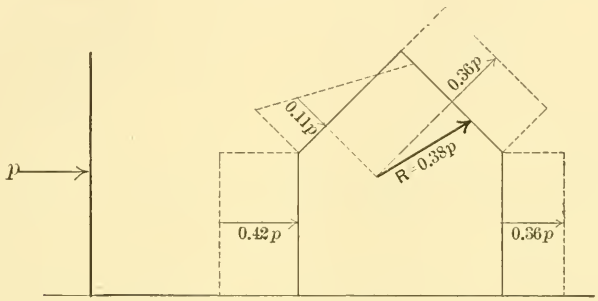

FIG. 18.

IV. THEORY OF TORNADOES.

The immediate cause of tornadoes and some of the characteristic phenomena attending their occurrence are well established from numerous records of observation of funnel-shaped clouds and sand storms on land, and water spouts at sea. The knowledge of the internal relations of velocity and pressure are dependent on the generally accepted mathematical theory* of William Ferrel, supplemented occasionally in recent years by the records of self-recording meteorological instruments that may be near the vicinity of such storms.

The conditions favorable to a tornado are an unstable equilibrium of the atmosphere caused by an excess of warm and saturated air accumulated under the colder and heavier strata above. The lower strata finally bursting through the upper one at some point and starting an upward flow, the region of ascending currents is kept warmer and consequently rarer, as long as it is supplied with air nearly or quite saturated. The latent heat which is given out by the condensation of the vapor in the rising and expanding air necessarily keeps up the general temperature far above what it would otherwise be.

* "A Popular Treatise on the Winds." Wm. Ferrel.

The great effect which the presence of aqueous vapor in the rising air has on its temperature is more clearly seen by the illustration of assuming a mass of air at sea level at temperature 27° Cent. and pressure 750 mm., to be transported upward without the addition or subtraction of any heat and noting the change it undergoes in temperature, due to the expansion under diminished pressure and consequent cooling. Assuming the three conditions, dry, half saturated, and fully saturated air, the temperature at various elevations and corresponding pressures is given in the table.*

	Elev. 0.° m. Pres. 750 mm.	1 280 m. 640 mm.	2 600 m. 544 mm.	3 750 m. 472 mm.	5 550 m. 375 mm.
Dry.....	Temp. = 27.° C.	13.3°	0.°	—11 2	
Half saturated ...	" = 27.° C.	13.3°	6.5°	0.°	—9.6°
Fully saturated ..	" = 27.° C.	21.2°	15.°	9.5°	0 °

The dry air and the half-saturated air expand and cool equally until the dew point of the latter is reached at an altitude of 1 280 meters, the temperature of each being reduced at that level to 13.3° Cent. The fully saturated air, kept warmer by the latent heat of the moisture, which is continually condensing, has the much higher temperature of 21.2° Cent. With further elevations, the dry air is reduced to a temperature of zero at an altitude of 2 600 m., but the half-saturated air, having passed its dew point, has now been kept warmer by latent heat and has a temperature of 6.5° Cent., the fully saturated air being at a temperature of 15°. The temperature of the half-saturated air becomes zero at an altitude of 3 750 m., and the fully saturated air is not cooled to zero until an altitude of 5 550 m. is reached.

From any slight disturbing cause, the rising currents soon run into rapid gyrations about the center, which generally extend from above downward, the process being an inversion of the familiar comparison of the case of water in a shallow basin running out through a hole in the center. The centrifugal force of this rapidly revolving pillar of air causes a rarefaction and consequent cooling of the air near the center which condenses the vapor and forms the water-spout, or the familiar funnel hanging from the base of the cloud. Unless the whirling motion has reached the ground and drawn up dust and débris, the outline of the funnel represents a theoretical line of equal pressure and equal

* Values in the table read from "Hertz' Graphical Solution of the Adiabatic Process" in "Modern Meteorology." Frank Waldo.

temperature, if the inflowing air is of a uniform degree of saturation; or, in general, it may be considered the locus of the dew point conditions of the ascending and revolving air currents. With an increase of velocity, the rarefaction extends further down, and the funnel lowers. The funnel is always an indication of the gyratory motion of the air, but not necessarily a measure of its action. With various degrees of saturation, different funnels would appear for the same velocity of gyration. With partially saturated air and the central part of the column sufficiently rarefied and cooled to be near the point of condensation, a small change in the gyratory velocity will cause the funnel to suddenly appear throughout the whole length, or as quickly disappear, making it apparently drop down from the clouds and draw back again in a capricious manner. With the air at or near the point of saturation, the cloud will appear very low, and a slight relief of pressure cause a general condensation in which the funnel is not distinguishable. Such were probably the conditions at St. Louis, as the relative humidity of the air was 0.94.

The water spout shown in Plate IX,* which was observed near Cape Cod, represents an exceptionally perfect example of the phenomenon, and is illustrative of the theory. It occurred about 12.45 o'clock on a warm and sultry day, lasted about 17 minutes and then disappeared, and was followed after several minutes by a second spout, which dropped down from the clouds at nearly the same place, but was not so large and lasted only a short time. There was probably but one column of gyratory air, which became invisible towards the end, when the air at the center became denser, due to reduction of velocity; but with a further increase in the velocity, from some cause, the rarefaction and condensation would again follow and the air at the center again become visible, appearing to the observer, however, as a second and different spout. The photograph was taken at an estimated distance of 7 to 10 miles, some six to ten minutes after the spout had been formed. The regular diameter and outlines of the column and its almost stationary position indicate a high degree of uniformity in the conditions of the immediately surrounding atmosphere. There was a great agitation and boiling of the water at the base. The column was estimated about a mile high and 300 ft. in diameter. The irregular form and progressive motion of the second

* Reproduced from a photograph copyrighted by Mr. J. N. Chamberlain.

spout show the less uniform conditions which prevailed near the end when the energy had been nearly exhausted.

The equations deduced by Ferrel are based on assumed conditions of no friction, either between the currents of air at different velocities, or between the revolving air and the surface, a gyratory velocity very great compared to the velocity of the radial or ascending currents, and a continuity of action sufficient to allow the gyratory motions

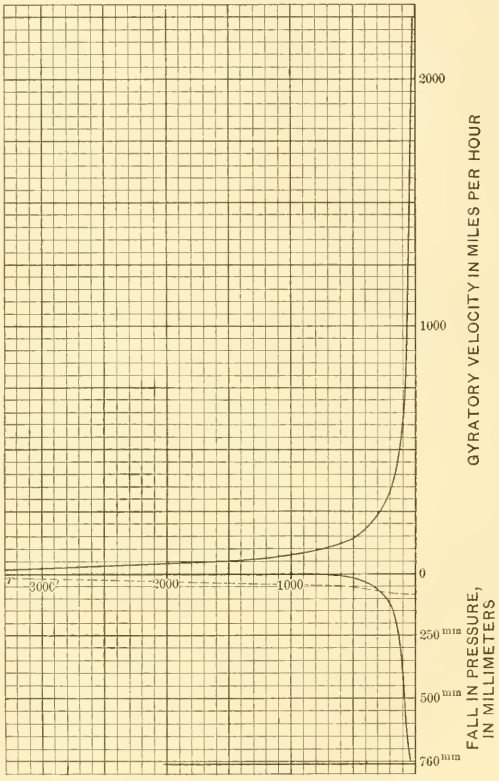

FIG. 19.

to become uniform. This purely theoretical treatment gives enormous velocities near the center with very low pressure, and a very rapid change for both velocity and pressure for varying distances from the center, which, as Ferrel repeatedly cautions, must be greatly modified for the effects of friction. With the gyrations brought to the surface, the velocities of the inflowing air currents are very small, as the cen-

PLATE IX.
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trifugal force tends to keep them out. To account for the great velocity of ascending currents, Ferrel assumes that the friction at the surface will greatly reduce the gyratory velocity, and consequently the centrifugal force there, and allow the side currents to rush into and rise in the central space of low pressure. The pillar of revolving air, with a hollow center extending nearly, but not quite, down to the surface, acts like a chimney through which the surface currents rush up with extreme velocity.

To illustrate more clearly the conditions existing in a tornado, the tabulated results for one of a number of examples worked out by Ferrel have been plotted, and are shown graphically in Fig. 19. The vertical line represents the axis of the tornado. The vertical ordinates to the upper curve give the theoretical gyratory velocities v in miles per hour, varying inversely as the distance from the center, and the vertical ordinates to the lower curve give the theoretical reduction in pressure p in millimeters, each corresponding to the distance r from the center of the tornado, laid off on the horizontal line. The extreme values near the center are wholly theoretical and would be very much modified by friction. The pressures at the base would probably be more nearly represented by the dotted line. The high velocities and corresponding intensity of pressure reached by even an approach to these theoretical results convey an idea of possible destruction that may be somewhat misleading as regards its amount, when considered in reference to structural work or buildings. The destructive work done by the winds must depend, not only on the velocity of the air, but also upon the volume in motion. The volume of air having this high velocity is very limited, the same mass revolving around very often. The time of one revolution for various particles of air, computed for the velocities and distances from the center as taken from the curves, appears in the following table and shows this more clearly:

Velocity—miles per hour.	Distance from center.	Time of one revolution.
	Feet.	Seconds.
100	730	34.2
120	610	21.7
150	485	13.8
200	370	7.9
300	245	3.5
400	180	1.9
500	145	1.23

Assuming, for illustration, that an imaginary rigid plane, extending any height above the surface, were suddenly thrust into a tornado to the center, the pressure on any point on that plane would be such as corresponds to the velocity and density of the particles striking at that point, but it would last only as long as the time of one revolution of such particles. In this case a pressure due to a velocity of 120 miles would last 21.7 seconds, while a pressure due to a velocity of 500 miles would last only 1¼ seconds. This is true in degree whenever a tornado encounters any considerable obstruction in its path. The pressure due to these high velocities may be exerted continuously on small objects, but only for brief periods on large and rigid bodies.

It is needless to say that any theoretical discussion is dependent on perfect or uniform conditions that are the exception in Nature; but the results may be taken to represent a type to which the actual occurrences are more or less similar and in rare cases attain, as in this instance of the water-spout. Even in this case the equations would apply only to the body and have to be largely modified for the base of the spout, where the conditions were not so clearly defined.

V. Application of Theory and Experimental Results to the St. Louis Tornado.

The indications in the St. Louis tornado point to a condition similar to the theory given by Ferrel, if very largely modified for surface conditions of friction. The very low barometric readings suggest the interior conditions of the tornado while the destructive action at the surface does not show evidence of that extreme force observed in some other tornadoes and which would necessarily accompany the gyratory velocities required to produce such a fall in pressure. Assuming even an approximate flow of air from all sides into the storm center with the velocity recorded at the Weather Bureau, that is, about 10 miles in 12 minutes, the resulting volume of air to be disposed of is enormous. The existence of a very low pressure at the axis of the tornado, allowing the ready escape of the air upward, would draw it in at the surface and might account for a great inflow from all sides.

In this instance, as is commonly the case in tornadic action, there were probably several tornado whirls, more or less completely developed, but not extending quite to the surface, which passed over the

district and created an area of very low pressure, with a resultant influx of lateral air currents at very high velocities from all sides, the latter being probably the immediate cause of most of the destruction. The records of the Louisville tornado, as given in the Weather Bureau reports, show that most of the damage there was due to the lateral currents toward the center. The general indications and a sequence of well-established incidents show very clearly that the damage to the St. Louis Bridge was caused by lateral currents rushing into the vortex which passed on the south side of the bridge as it progressed eastward.

Allowing for the heavy proportion of the damage due to flying débris acting as projectiles, and to the direct action of the wind in blowing in one wall and successively taking out the others, there still remains a large percentage of destruction which was the result of the explosive action due to the difference in pressure of the air on the inside and outside of buildings. There were numerous instances of partial destruction which showed this action very clearly. The immediate cause for this difference in pressure is a matter of some speculative interest.

The great reduction in atmospheric pressure in the center of tornadoes is a possible cause. While, however, the possible destructive action of such variations in pressure is enormous, the extent to which it is realized is dependent entirely upon the rapidity of the change. If the rate of change is gradual enough to allow the confined air to escape and equalize the pressure inside of the house, there will be no damage due to this cause. That this change of pressure is a more or less gradual process is evident from the fact that the variation of 2.4 ins. in the mercury barometer, which is equivalent to 168 lbs. per square foot, would, if instantly applied, completely burst open any ordinary house.

The fact that the low reading on the aneroid in the storm was noted before the advent of the extremely violent wind, and also the marked effect on the barometer at the Weather Bureau, are further indications that this change in pressure was a gradual one in the instance. Assuming that the effect of a possible reduction of 3 ins. in the atmospheric pressure, as measured by a mercurial barometer, is felt at the distance of a mile, and that the tornado moves at the rate of 40 miles per hour, the entire variation in pressure would be effected at

any one point in 1½ minutes. To equalize the pressure for such a change, about one-tenth of the air confined in a building must escape. For an ordinary room, say 20 x 15 x 10 ft., having a capacity of 3 000 cu. ft., this would mean a flow of 300 cu. ft. in 1½ minutes, or an average rate of 200 cu. ft. per minute. If this rate is assumed as not uniform, but as having a possible maximum at some time of twice that amount, the flow must be 400 cu. ft. per minute. Under a difference of pressure of 10 lbs. per square foot, the flow of air through an ordinary 6-in. stove pipe may be about 500 cu. ft. per minute. Through an open fireplace with an ordinary 9 x 9-in. flue, the flow of air may be 1 000 cu. ft., or a single window with an opening of 1 in. will accomplish the same result. A house that is entirely closed, in the ordinary sense of the word, would have an amount of leakage through the doors, windows, chimneys or ventilating flues that would go far to equalize any but the most sudden change in pressure.

The observations of Prof. Langley show that the wind under ordinary conditions is subject to continual fluctuations in velocity varying from 20% to 50% from the average, and that these variations become greater at higher velocities. The conditions prevailing in a tornado must give rise to the most violent local action of the wind. The internal irregularities which are caused by the motion of great volumes of air rushing with accelerated velocity towards a common center are rendered still more complex by the usual presence of aqueous vapor at its critical point with the attendant dynamic changes due to the expansion, cooling, condensation and latent heat. The presence in the air of the aqueous vapor, with these transformations gradually but continually going on, is recognized by meteorologists as the chief cause of local disturbances of the atmosphere. That a storm with the air at the point of saturation will cause much greater damage than one under similar conditions as to intensity of wind, but with the air dry, as noted in a previous discussion* before this Society, is further evidence of the greater irregularity of the wind due to this cause. If the velocity of the ordinary wind will vary 50% from the average, it is quite probable that the velocity of the inflowing currents of air at the base of a tornado may vary locally from nothing to double the average or more, and that there may be, at any point, a momentary calm followed immediately by a surging mass of air with a velocity

* *Transactions*, Vol. xxxiii, p. 214.

approaching or equal to that due to the gyratory motion of the tornado itself. When these irregularities in the wind are further complicated by the effects of the broken surface conditions due to the houses and streets of a closely built city, with the attendant obstructions, eddies and deflections of the currents, the motion of the air must become infinitely complex and capable of almost any vagaries.

The apparent inconsistency so frequently seen of a weak and frail structure with equal exposure escaping close to the general destruction of a stronger building is the most conclusive evidence of the unequal action of the wind.

If the characteristic effects of the wind, as known by observation and experiment at ordinary velocities, are maintained and correspondingly intensified for the high velocities attained for brief periods over limited areas by this gusty and irregular action, the destruction is readily explained.

The familiar sight of the little whirlwinds that suddenly appear on a windy day, and move along the road or street for a few minutes, picking up leaves, dust, or paper, give but a faint idea of the possible effects of the many local whirls, of varying magnitude, that must be continually formed when the atmosphere is in such an extremely agitated and unstable condition. The meeting of sharp extreme gusts of wind will create a whirl with an instantaneous fall of pressure over a small area at the axis, the latter being not necessarily vertical, but possibly horizontal or at any inclination. If such a whirl be formed with the axis against a building, the sudden relief of pressure over a very small area will cause an immediate explosion of part of the building.

The wind blowing into a building will quickly pack the air and create a pressure and blow out the weakest accessible part, either wall or roof. This is particularly effective with large or high spaces unbraced by cross-walls or partitions.

The suction found to be present on the leeward side of obstructions to the wind may account for a great amount of damage. A wind with an average velocity of only 80 miles per hour might under extreme conditions have fluctuations of 120 to 160 miles per hour. Assuming the values found by Irminger to be approximately correct, such a wind blowing over the top or past the side or at an angle against a building would give a suction of 20 lbs. to 40 lbs. per square foot, acting instantaneously and giving no time for the pressure to equalize. The same

experiments show that the wind blowing over the sloping roofs so generally found on churches will create a suction that tends to raise the covering off of the trusses, an occurrence that was observed in numerous instances. The frequently observed stripping of patches of slate out of sloping or mansard roofs is also readily accounted for by this action.

The very general and repeated evidences as to the variable action of the wind suggest the desirability of further observations of velocities recorded at shorter intervals than the nominal passage of every mile of wind as is customary in meteorological practice. A wind registering every 45 seconds is necessarily interpreted as representing a uniform velocity of about 60 miles per hour, while in reality there may be velocities of 90 or 100 miles or more in several successive gusts of five to twenty seconds' duration, long enough to overcome the inertia of the heaviest structure. It is these destructive velocities that chiefly concern the engineer, and any deductions as to pressure made from ordinary velocity records may be very misleading.

The valuable records of the Weather Bureau could be made of more service to the engineer if supplemented by a knowledge of such fluctuations from the average velocity as may exist in severe storms and under varying conditions as to temperature, humidity or barometric pressure. Such information could be readily obtained at any of the regular stations by occasional observations recorded on an additional chronograph adapted to such service.

The salient features of the St. Louis tornado may be summarized as follows:

The passage of a local area of extremely low atmospheric pressure accompanied by a great inflow of violent and gusty lateral air currents, with an intensity of pressure estimated at 60 lbs. per square foot in one instance, and 85 to 90 lbs. per square foot in another.

In general the intensity of pressure increased greatly with the altitude.

VI.—Necessity of Wind Bracing for High Buildings.

Much of the destruction in St. Louis was undoubtedly caused by an intensity of wind pressure that it would be neither possible nor expedient to provide against in ordinary structures, but much of it

was also due to weak construction. A general observance of the ordinary requirements for good building work would largely decrease the damage due to such storms. The great amount of explosive action was largely due to the comparative weakness of ordinary walls against pressure exerted from the inside of buildings. A more efficient anchorage of the walls might limit this explosive action to the windows. In numerous instances the windows were blown in on the windward side, while the entire wall was blown out on the leeward side. Brick walls are materially stronger if well bonded with the vertical joints filled with mortar, and a wall laid in cement will undoubtedly withstand a greater lateral force than one laid in lime mortar. It is worth noting that the walls of the buildings of the Union Depot Railway plant left standing (Fig. 1, Plate IV) were laid in cement, while the older buildings, which were entirely wrecked, had walls laid with lime mortar. The great damage done to the churches calls attention to the great exposure of the steep and lofty roofs supported on high and comparatively thin and unbraced walls. Heavier buttresses or independent steel column supports, with bracing for the roof trusses, would materially increase the safety of such structures. In general, the buildings with large areas of unbraced walls have suffered most.

The lofty office buildings common to the large cities represent an expenditure of money that justifies careful provision against any destruction that may arise from even exceptional wind pressures. The question as to what would be the effect of a tornado on these high buildings is one that has probably occurred to every engineer and architect.

The periodic prevalence of these storms emphasized by the recent calamity in St. Louis, by the destruction in Louisville in 1890, and by a similar storm in Little Rock in 1894, and in Kansas City in 1886, gives a somewhat broader public interest to this question, and appears to call for its serious consideration. The evidence of the work of the wind in St. Louis suggests as an immediate answer to the question that it will depend largely upon the nature of the metal framework in the building.

The high office building represents the outcome of an evolution in architectural and constructive design dictated by the commercial necessities of the age. The tendency to the concentration of business in-

terests within small areas, the excessive high values of land, and the necessity of realizing an adequate return on the investment, demand a building with many floors and the maximum rentable space on each floor—a high building with thin walls. The replacement of the heavy exterior masonry by the lighter veneer or curtain walls and the consequent gain in available floor space has been made possible by the use of an iron or steel framework, primarily introduced to carry the vertical loads only, but gradually modified and strengthened in accordance with an increasing recognition of the need of providing lateral strength and stiffness against wind and other destructive forces. There still exists, however, a great diversity in the treatment of this feature of the design.

The metal framework of a building is somewhat generally called the "skeleton" and sometimes a "cage." If both of these terms are to be retained in this special sense, a convenient distinction can be made by some restriction in their use suggested by the words themselves.

Skeleton is a term clearly descriptive of that type of construction to which it was first applied, a simple framework of columns and beams whose efficiency is dependent largely on the existence of exterior walls and partitions which brace the building, and hold the framework in position, just as the utility of the human skeleton is dependent on the covering of sinews and muscles that hold the component parts together. On the other hand, the light framework of an ordinary wire cage bound into one compact unit is suggestive of an inherent strength and elastic resistance that renders any covering an incident rather than a necessity. Cage is a term peculiarly descriptive of that type of construction represented by the most advanced and approved practice, a framework of columns and beams, spliced at the joints, riveted at the connections, stiffened by an efficient bracing of rods, portals and gussets that makes it independently safe against any external force, leaving the thin and light exterior walls with no duty except that of providing protection and ornamentation for the building.

The effect of an extreme wind pressure on a high office building with curtain walls must depend largely on the extent to which the frame of that building partakes of the nature of the skeleton type or the cage type of construction.

The possible work of destruction of a tornado may appear more clearly if, as Ferrel suggests, the column of rapidly revolving air is likened to a tall flue, with heated and rarefied air in its interior. If the access of air is cut off from the lower central part by the shell of gyrating air extending down to the surface, the lateral currents and ascending currents in the interior will be of no violence, but with a somewhat free access of air below into the rarefied interior, on account of a decrease by friction of the gyratory velocity near the surface, the inrush of lateral air currents becomes extremely violent and the velocity of the uprush of air in the interior becomes enormous. In the former case the destruction is mainly due to the excessively high gyratory velocities; the destruction is complete, but the path narrow. It is the condition that may prevail in open country with but few objects to destroy the energy of the tornado. In the latter case the destruction is largely due to the violent lateral inrushing currents. The path is wider, and the force not so extreme. It is the condition which must prevail in any compactly built city, owing to the great friction of the air arising from the irregularities due to the many buildings.

The first high isolated building encountered will feel the full force of the gyratory velocity, but the resistance of the building destroys this velocity and the work of destruction wrought on that building must represent an equivalent diminution of energy in the lower section of the tornado, which can only be renewed by its further unobstructed progress during such appreciable time as is necessary to restore the gyratory velocity. A succession of high buildings will prevent such recovery of velocity.

The destructive power of a tornado on massive building work due to these excessively high gyratory velocities is therefore soon exhausted, but the wind pressures due to the violent currents rushing in from all sides are only intensified thereby.

If a tornadic storm with a well-developed whirl should pass through the section of any city containing very high buildings, the general level of the top of the lower buildings becomes equivalent to the ground surface, and it seems fair to assume as the result the same general action that has been found near the surface, modified or intensified in its irregularity according to the degree of uniformity in the general height of the majority of the buildings. There may be the extreme pressures due to the gyratory velocity of the tornado

proper exerted over a limited area and for a very limited time. There will be a far wider zone of lateral inrushing winds at high velocities lasting throughout the progress of the tornado and attended by the additional complications that may arise due to the concentration of air currents in the deep valleys formed by the streets between the buildings. The probable result would be an extremely variable and intense action of the wind about the tops of the lower buildings, the same action concentrated locally at about that level on the higher buildings, accompanied with a general severe pressure over the entire exposed area of the latter, this latter pressure probably being a maximum near the top or at least some distance above the general level where the friction is not so great.

A characteristic feature of the St. Louis tornado, and one which, judging from records and published views, is also common to other tornadoes and violent hurricanes, is the general destruction of the ordinary brick and stone walls. Regardless of the sequence in which they may explode outward or are blown inward, and of a possible difference of opinion as to whether the explosion is due to a plenum, a vacuum or a suction, the essential fact remains that the walls do very generally fail.

Assuming a similar action of the wind, the buildings of an average height will probably have the walls at the top or exposed corners destroyed, or, if particularly weak, may be shaken down. The buildings above the average height would be very liable to have part of the walls at any level blown in or taken out. An office building with the curtain walls of one or more stories removed would support the remaining enveloped superstructure precisely in the manner of the grain elevator before it was struck by the storm.

If, now, the building is of the pure skeleton type, it will have only the elements of stability that existed in the case of the elevator—its weight—above the floor in question, and possibly some additional bracing of a more or less uncertain value, and under the action of even such pressure as may exist at some distance from the vortex of the tornado, it will fail, just as the elevator failed; it will topple over and fall to one side or towards one corner on the floor below. Instead, however, of landing on a massive stone foundation, the thousands of tons of weight of the three, four or six stories, as the case may be, of the upper section of the building will fall with a crushing force, con-

centrated on the leeward side, on the section below. The heavy oak girders under the leeward edge of the elevator were mashed into a buudle of splinters, while the windward edge was held some distance above the foundation. As the striking force of a freely falling body is equal to the product of its weight multiplied by the distance through which it falls, about 12 ft. in the case of an office building falling one story, the resulting pressure on some of the columns may easily be ten to twenty times the load they were designed to carry and several times their ultimate strength; the result must be a collapse of part or all of the lower section, with a possible toppling over of the upper section to one side into the street or on a lower adjacent building.

If the building is of the cage type, it will stand safely under a wind pressure that will destroy the skeleton building. While the failure of the walls at any story may reduce the rigidity somewhat, it cannot affect the strength of a framework designed without placing any dependence on the covering. Such a framework will readily carry the lateral stresses from the upper section to the section below.

If the pressure should reach a destructive intensity, the exact line of yielding of a cage frame is not so clearly defined. The tendency to lateral displacement will be a maximum at some one story, depending on the distribution and cumulative effect of the wind pressure aided possibly by the weakening due to localized failure of walls or partitions. As the frame is of a gradually varying strength from the top down, the distortion can hardly be confined to one level, but would probably involve the members of the adjacent stories, the effect being a general racking or leaning of the building. With strains near the ultimate strength, the failure at some point may concentrate a distortion at that level, and the upper section of the building may be pushed to one side and ultimately settle down on the floor below.

The essential difference lies in the fact that a wind of sufficient force and duration to push the upper section of a building to one side a distance about equal to the width of a column may cause total destruction in a skeleton building, while a cage under the same circumstances may suffer only a local damage that can possibly be repaired at a comparatively small cost. In a skeleton building, the instant the columns are pushed beyond the critical or balancing point, the weight is reversed in its action from an element of safety to an almost unresisted

element of destruction. With a cage type of construction the weight of the building after some displacement has taken place also acts with the wind as a destructive agent, but not unresisted. The work that must be done in the necessary bending, twisting and general distortion and breaking of the metal in the columns and beams must largely absorb the energy of the falling mass and have the effect of letting it settle down on springs. The local peculiarities of the building, the unequal distribution of the wind pressure, and the changing direction of the wind, make it more than probable that such failure will not be symmetrical, but will have a torsional effect on the upper section of the building.

However difficult it is to foresee the many possibilities, it is safe to assume that in one way or another the framework will hang together sufficiently to prevent any considerable part of the building from falling down bodily on to streets or buildings below. Even under the most extreme conditions it is difficult to conceive how such a building, or a large part of it, can entirely collapse. The general destruction of windows and walls will greatly relieve the wind pressure, the frame, partly bent, twisted and distorted, must still hold together. The chances are that most of the occupants will escape alive and many uninjured. The most striking feature of the St. Louis tornado is the countless number of hairbreadth escapes and the very small number of people killed inside of houses unless by the entire collapse of the structures; incredible as it may seem, under such extreme conditions, the fatalities attending only local failure of a building are comparatively few.

The effect of a destructive wind pressure on any high building with curtain walls may be assumed to approach that outlined above in proportion as its framework partakes of the nature of a skeleton or cage type of construction, using these terms in the restricted sense indicated in this paper.

The destructive effect of the total collapse of buildings has been too frequently noted to require further mention. The method of failure of the grain elevator, taken in connection with the view of the wreck of the skeleton framework in Fig. 1, Plate VII, indicates what might happen to a high building of the pure skeleton type if brought to the point of failure. The assumed action of the cage type of building is dependent on an efficiency in general design, and particularly in the

detailing of connections which can be readily attained if the necessity for it is recognized. In the absence of any definite tests of full-size typical details used in the structural work of buildings, the action of the metal under extreme distortion must be estimated from the results shown by sample specimens, verified by occasional opportunities to notice its behavior under accidental tests of great severity that may be caused by collisions or derailments on or near bridges and viaducts. The riveted joints mentioned earlier in the paper show what may be expected in details involving similar principles of design.

The possibility of a high office building being actually subjected to a destructive wind pressure has often been considered largely in the light of a theory. The St. Louis tornado passed within less than a mile of the office buildings in that city. Fortunately it made no test of the buildings, but it has left some definite evidence of the possible force of the wind and of the action of this force on the materials of construction. While it raises anew the question as to the amount of wind force which should be provided for in designing high buildings, it raises with more emphasis the question as to the method of providing for this force after its amount has been assumed. Any dependence placed on curtain walls and partitions for lateral strength is open to very grave question. The rigidity imparted to a building by the simultaneous action of the total mass of material under ordinary conditions is no indication of the ultimate strength that may be developed at a critical moment, and the very general failure of the walls under extreme wind pressure further destroys any certainty of such assistance as might be otherwise relied upon. The elements of safety against wind force, exclusive of the strength that may come from the walls and partitions where they exist, are the stability due to weight alone, stability due to the strength and stiffness of the frame, and, when the force is a sudden one, the inertia of the mass resisting motion.

It may be of interest to estimate just how sudden and how shortlived the force must be to justify placing any dependence on the inertia of the structure for safety. The force required to set in motion and move over a given distance any mass, otherwise balanced, is capable of exact computation if the time allowed for such motion is known. The equation is derived from the law for falling bodies and is $F = \frac{2\,w\,d}{g\,t^2}$, where F is the

total force, w the weight moved in pounds, d the distance moved over in feet, t the time in seconds, and g is 32.2.

The following table, computed from this formula, gives the force required to overcome the inertia of a ton of 2 000 lbs. and move it varying distances in times varying from one second to thirty seconds.

FORCE IN POUNDS REQUIRED TO OVERCOME THE INERTIA OF AND MOVE A MASS OF 1 TON.

TIME IN SEC.	DISTANCE MOVED.									
	1 in.	3 ins.	6 ins.	1 ft.	2 ft.	4 ft.	6 ft.	8 ft.	10 ft.	16.1 ft.
1	10.3	31	62	124.22	248	497	745	994	1 242	2 000
2	2.6	7.7	15.5	31	62	124	186	248	310	500
3	1.15	3.4	6.9	13.8	27	55	83	110	138	222
4	0.64	1.94	3.9	7.7	15.5	31	46	62	77	125
5	0.41	1.24	2.4	4.9	9.9	19.8	30	40	49	80
6	0.28	0.86	1.72	3.4	6.9	13.8	20.7	28	34.5	55
8	0.16	0.48	0.97	1.94	3.8	7.7	11.6	15.5	19.4	31
10	0.10	0.31	0.62	1.24	2.4	4.9	7.4	9.9	12.4	20
15	0.046	0.14	0.27	0.55	1.10	2.21	3.3	4.4	5.5	8.9
20	0.026	0.078	0.155	0.31	0.62	1.24	1.86	2.5	3.11	5.0
30	0.012	0.035	0.069	0.138	0.28	0 55	0.83	1.10	1.38	2.22

Assuming as an illustration the weight of a ton suspended as a pendulum by a very long cord, then to swing it 1 ft. in one second will require a force of 124.2 lbs., while the mere pressure of 1¼ lbs. will accomplish the same result if the time allowed is 10 seconds, or about the average duration of a gust of wind in Professor Langley's experiments. Applying the figures in the table to the case of a narrow building, say 32 ft. wide, and assuming the upper section 100 ft. high by 100 ft. long, having thus an exposed area of 10 000 sq. ft., to weigh 5 000 tons, then the force necessary simply to overcome the inertia and move this part of the building the respective distances of 1 in. or 1 ft. or 16 ft., in various intervals of time, is equivalent to a pressure per square foot of the exposed areas as follows:

t.	$d = 1$ in.	$d = 1$ ft.	$d = 16$ ft
1 second	5.2 lbs. per sq. ft.	62.1 lbs. per sq. ft.	1 000 lbs. per sq. ft.
2 "	1.3 " " "	15.4 " " "	250 " " "
3 "	0.5 " " "	6.9 " " "	111 " " "
5 "	0.2 " " "	2.5 " " "	40 " " "
10 "	0.05 " " "	0.6 " " "	10 " " "
15 "	0.02 " " "	0.3 " " "	4.4 " " "

These figures will readily indicate how great a resistance the inertia of a building may offer to the motion necessary to overturn it under the action of a brief gust of wind, and how comparatively little this resistance becomes to such motion as is necessary merely to push it over on its supports. To overturn the building in 10 seconds a pressure of 10 lbs. per square foot is necessary to give it the necessary motion in addition to the force required to overcome its stability. The resistance of inertia for a movement of 1 ft. against a gust five seconds in duration will be 2.5 lbs. per square foot, and for 10 seconds it will be only 0.6 lb. per square foot. For shorter periods the value of inertia becomes very high, but may on the other hand be entirely overbalanced by the cumulative effect of the vibrations of the building acting in rhythm with the pulsations of the wind. Experiments on Chicago buildings under heavy winds show the time of a complete vibration to be about two seconds. The resistance of inertia to the destructive effect of brief but intense pressure, such as is due to the gyratory velocity in the vortex of a tornado, is fortunately very great.

Stability due to weight alone is proportional to that weight and to the breadth of base of the support. Its value as an element of safety is a most definite one, and may be sufficient. Considered with reference to overturning, a large elevator or building may be safe beyond all question, yet with reference to its column supports the same structure may be in comparatively unstable equilibrium, as a relatively small movement of the center of gravity will throw it out of balance. The total force required to overturn a building of a given weight increases directly with the breadth of that building, but the total force required to push it over on its supporting columns is a constant depending solely upon the height and breadth of base of those columns, and is independent of the dimensions of the building, of the number of supporting columns, or the material they are made of. Any structural member that is used simply as a prop or support can have only such value as is incident to that use, whether it is made of wood, of stone, of cast iron, or of steel.

The elements of strength and safety inherent in a well-designed cage built of the proper material, with all its members thoroughly riveted together, are present in that frame in greater or less degree, until it is torn or cut apart piece by piece. A steel frame built to be

safe for a wind pressure of 30 lbs. per square foot proportioned by unit strains of one-half the elastic limit would probably withstand a pressure from 40 to 80 lbs. per square foot before the frame yields. This range depends largely on the care with which the connections have been detailed, the extent to which possible unequal settlement of the foundations has already overstrained the frame, and on the reduction of the effective surface exposed to the wind by the destruction of the walls in the panels between the framework, leaving part of the wind to blow through unresisted.

The details of construction that provide lateral strength and safety against an assumed wind pressure are of the first importance. The subject of this paper, however, suggests a further consideration of these same details of construction assuming that they may be strained by wind pressures beyond their safe limits. If a building is never under any circumstances to fail, the problem is completely solved as soon as it is designed to stand under the assumed pressure. Assume that it may some day be brought to the point of yielding, and immediately some pertinent questions arise as to the possible results.

While the destruction and loss of the upper section of a building may be a matter of serious consideration to the owner, the disposition which a tornado would make of that section of the building may be an equally or more serious matter to the adjoining property-owners. If it is impossible to foresee the extreme force of the elements or impracticable from economic reasons to provide against them entirely, it certainly is rational to make such modifications in a design as will reduce the possible disaster and damage to a minimum. A very material increase of safety in this direction can generally be secured at a comparatively small additional expense, depending largely on the attitude of the designer to the problem. The design of a building to be subjected safely to a given wind pressure and never to any more is a definite problem involving only arbitrarily fixed working stresses. A design of that same building for the same condition of safety but with the further recognition of the fact that it may be exposed to destructive pressures and with an effort to develop the ultimate strength and resistance of the material in the cage to resist those pressures, is a problem that will develop some additional considerations.

A destructive lateral force exerted against the upper section of the building will not be lost or dissipated but must follow some well-de-

fined path till it reaches the foundation. If a building is to fail laterally, then the ultimate strength of members under the action of lateral forces becomes of the first importance. Upright members are no longer simply columns, but are more properly considered as vertical beams carrying some initial load, and, viewed in that light, must have all the essential elements of a good beam. The unequal straining and successive failure of the rivets, due to their unsymmetrical distribution in the connections, may become an important element of the design when the stresses are sufficient to overcome the averaging effect of the frictional resistance. The relative values of the ultimate or elastic limit stresses may suggest details at the connections somewhat different from those indicated by the fixed ratios of assumed working stresses.

A brief analysis of possible results applied to the definite circumstances and conditions of any particular building may suggest probable failure along one or several well-defined lines, and as readily suggest modifications that will materially increase the strength of the structure, or at least define and limit the amount of destruction.

The amount of metal required for an efficient system of wind bracing is but a small part of the weight of the metal in the entire frame, and the cost of the latter is only about 10% to 20% of the expenditure for the entire building, exclusive of the site. The cost of the wind bracing can represent, therefore, only a very small proportion of the total capital invested. When it is considered that any additional metal used to strengthen the cage as a precaution against wind force is equally effective against possible damage due to earthquake shocks or to the unequal settlement of the foundations, and is also an additional margin provided against the weakening effect of corrosion, the slight increase in cost must appear trifling as compared to the amount of the entire investment and the additional protection secured for the property.

It is somewhat unfortunate that the merits of the design of the framework are not so readily apparent to the investor, and that this part of the structure is of necessity immediately covered and permanently concealed from view. If the difference in strength and security due to the construction of the frames of some of these great buildings were as generally evident, as, for instance, the difference in strength due to the varying thickness of solid masonry walls was in

older forms of construction, there would probably be a more general recognition on the part of the owners of the need of securing the best type of framework.

A discussion of the safety of high buildings is applicable to other high structures, such as chimneys, shot towers, water towers, etc., and suggests that the development of the cage construction in buildings to its present advanced type makes it equally available for other structures of the kind named above. Monuments built with no consideration of expense will find ample security in their weight, but for any high structure in which cost and security are both of importance, the cage type of construction is thoroughly applicable and may have special advantages. The saving of material in the walls, and particularly in the foundations, may more than equal the additional cost of the steel work when designed for the same strength and security. The objection to any open tower built of structural metalwork in a city on the score of its inherent ugliness is removed by adopting such treatment as the architects have developed in the design of high office buildings. Any shaft or high structure that has lines of stability can be readily supported on a steel cage that will not interfere with its outlines, with probably a great gain in safety.

The amount of wind pressure to be provided for in the design of high buildings will no doubt be variously estimated, depending on the weight given in the judgment of the designer and of the owner of the building to the probability of exposure to such pressures. The statistics as to the frequency of tornados given in the appendix show that the possibility of their occurrence cannot be entirely disregarded without assuming some appreciable risk. While the atmospheric conditions which are favorable to their formation are more frequent in some regions than others, it is impossible to feel assured of entire immunity from their occurrence in any city. Tornadoes usually occur as local manifestations accompanying severe storms of great extent. On the date of the Louisville tornado there were ten others in the four adjacent States. On April 11th and 12th, 1893, there were nineteen tornadoes in ten States attending severe storms, reaching from Mississippi to Michigan. The St. Louis tornado was but one of a number accompanying a general storm that moved through Missouri and Illinois. As far as known it was not more violent than many others that have been observed. Its great destructiveness was merely incidental

to the fact that its path crossed a territory embracing a large and closely built city. It gave evidence that wind pressures existed at least equivalent to or greater than 20 lbs., 60 lbs., and 85 to 90 lbs. per square foot over considerable areas. Whatever the actual distribution may have been, the effects were those of such pressures uniformly distributed over the areas of the respective structures. These pressures were measured by their results in exactly the same manner in which they are ordinarily assumed to act, with the consequent elimination of all uncertainties usually involved in readings of pressure gauges or deductions from anemometer records, and they are to that extent positive and definite. In addition, there were indications that a pressure of somewhere from 20 to 40 lbs. was quite general over a comparatively wide area in, or adjacent to, the path of the storm, and that the pressures at higher altitudes were more severe than those measured.

In view of these facts it appears to the author rational to assume:

First.—That the safety and interests of the community and of the owner of the building require a recognition of a wind pressure of at least 30 lbs. per square foot against the exposed surface of the building, with an additional local provision of 50 lbs. for several stories near the top; and that this amount should be safely taken care of by some positive and definite provision in the construction of the frame.

Second.—That the vast interests at stake, the amount of capital invested and the comparatively small additional expense necessary would suggest to the owner the desirability of increasing the provision to 40 lbs. per square foot.

Third.—That the other uncertain elements of safety due to the ultimate strength of the material, the inertia of the mass, and the bracing effect of walls and partitions, should be recognized only as providing against the uncertain and possible higher pressure of the wind which may occur.

The chief justification of much that seems bold or questionable in the construction of some high buildings lies in the fact that, as yet, none have failed. If the safety of such great structures is to be determined entirely by the logic of the fitness of the survivor, based on a brief and favorable experience, rather than by a rigid analysis, by tried and accepted principles of engineering design, it may ultimately lead to some very deplorable results.

By such a test the little summer pavilion in Lafayette Park must take precedence over the approach to the Eads Bridge, for it survived the tornado and is standing yet.

The author is indebted to Mr. Willis L. Moore, Chief of Weather Bureau, and to Mr. H. C. Frankenfield, Local Forecast Official, for their continued courtesy in furnishing the use of records and information of that department; to Mr. A. H. Fredericks, President of Board of Assessors of St. Louis, for the data relative to general storm damages, and to many others, too numerous to mention, for their kind assistance in securing much of the detail information that appears in the paper.

APPENDIX A.

THE TORNADO OF MAY 27TH, 1896, AT ST. LOUIS, MO.

ABSTRACTED FROM REPORT OF H. C. FRANKENFIELD, LOCAL FORECAST OFFICIAL, IN *Monthly Weather Review*.*

The tornado which passed through St. Louis late in the afternoon of May 27th was the culmination of a protracted period of abnormally high temperatures, intensified during the latter portion of the time by unusually high humidity. From April 9th to May 27th, both inclusive, a period of forty-nine consecutive days, the mean temperature at St. Louis varied from 2° to 21° above the normal.

At 8 o'clock, May 27th, the weather map showed the pressure to be low throughout the West. The position of the state of Missouri in the southeast quadrant of the storm area, combined with the isothermal conditions, the high humidity, and the high temperatures, indicated the occurrence of severe local storms within a short time. At St. Louis at 8 o'clock, the pressure was 29.92 ins., the temperature 70°, and the relative humidity 94 per cent. By 14 o'clock the barometer had commenced to fall rapidly, and the winds had changed to southeast, with slowly increasing velocity. The fall in pressure was intermittent, but at the same time persistent, and by 18 o'clock the reading was 29.59 ins., a fall of 0.28 in. since noon, and a fall of 0.09 in. during the twenty minutes immediately preceding. The winds continued from the southeast with gradually increasing velocity until 17.45 o'clock, when they changed to east-northeast, with a sudden increase in velocity, reaching 45 miles per hour from 17.55 to 18 o'clock.

* Records are given in standard time, which is 1 hour 1 minute faster than local time.

At 15.45 o'clock the temperature commenced to fall, and by 18 o'clock had fallen 9° to 77°. The clouds slowly increased in density, and at 15.55 o'clock the sun was obscured. The character of the clouds changed about this time to cumulus, but of a very peculiar formation. The whole sky was compactly covered with small cumuli of almost perfect hemispherical shape, but with the rounded portions underneath. Their color was a dark gray, with deep shadows on the sides farthest from the sun. By 16.30 o'clock these clouds had settled into a uniform covering of stratus, which commenced to assume a light green color in the extreme northwest, spreading more toward the west and north. Thunder and lightning commenced at 17.06 o'clock, and rain in the form of large, scattered drops, at 17.43 o'clock. At 18.04 o'clock there was a marked increase in the violence of the storm, although from 18 to 18.10 o'clock the winds changed again to southeast, with decreased velocity of from 33 to 36 miles per hour. During this period the barometer rose 0.08 in., to 29.67, and fell almost instantly 0.10 in., to 29.57. It again rose 0.10 in. in less than five minutes to 29.67. During the next fifteen minutes (to 18.30 o'clock), it fell 0.31 in., to 29.36, and then instantly rose 0.40 in., to 29.76. It then continued in a series of sharp oscillations of from 0.05 to 0.10 in., until 22 o'clock, when the oscillations became smaller, ceasing finally at midnight, when a steady rise commenced.*

The winds at 18.10 o'clock once more changed suddenly, this time 180° to the northwest, and with greatly increased velocity, reaching 80 miles per hour from 18.15 to 18.20 o'clock, with an extreme velocity of 120 miles per hour at 18.18 o'clock. At 18.20 o'clock the direction once more changed, this time to the northeast, with a decided decrease in velocity, falling to 7 miles per hour at 18.55 o'clock.

The storm entered St. Louis from the west. The time, as nearly as can be estimated, was 18.10 o'clock.

The path through the city was almost exactly in a due easterly direction, reaching the Mississippi River, about 6 miles distant, at 18.20 o'clock, showing a progressive velocity of about 36 miles per hour.

* Note added by Mr. Frankenfield, June 23d, 1896: "I have just learned of the height of the barometer, within a reasonable degree of accuracy, in or very near the center of the track of the tornado at the time it moved through Lafayette Park. It was in this park that the storm was at its height. An aneroid barometer, with a metrical scale, was brought to me to be reset, and I was informed that it was the property of the widow of the late Richard Klemm, ex-Park Commissioner of this city. The family live on Missouri Avenue, immediately fronting the park, and a son of Mr. Klemm read the barometer as the storm struck their place. He called the attention of his mother to the remarkably low reading, 680 mm., or 26.78 ins. Allowing for difference in elevation and reduction to sea level, this would indicate a reduced reading of 27.30 ins., or 2.05 ins. lower than observed at this office."

APPENDIX B.

CORRECTION FOR OBSERVED WIND VELOCITIES.

The velocity of the wind is very generally measured by some form of the Robinson cup anemometer. From early experiments it was found that the distance passed over by the center of one of the revolving cups would, if multiplied by three, give about the velocity of the wind, and the wheels and recording dials of the instrument were geared to read wind velocities directly by taking into account this factor of reduction. Later experiments have shown that with anemometers of the size commonly used this ratio is erroneous, and the indicated velocities are about 20% too great, but no change has been made in the recording device and the "wind observations published by the various meteorological institutions at the present time have only a relative, but not absolute, value. It is very probable that many experiments on the relations of wind velocities to wind pressures have been made in which this anemometer correction has not been properly applied."

Professor Marvin has determined the correction to be applied to the readings of the standard form of anemometer used by the Weather Bureau. It is expressed by a logarithmic formula by which the following table taken from his report on Wind Pressures is computed:

CORRECTED WIND VELOCITIES AS INDICATED BY ROBINSON ANEMOMETER.

[Miles per hour.]

Indicated velocity.	0	1	2	3	4	5	6	7	8	9
0	.....	.....	.....	.....	.....	5.1	6.0	6.9	7.8	8.7
1	9.6	10.4	11.3	12.1	12 9	13.8	14.6	15.4	16.2	17.0
2	17.8	18.6	19.4	20.2	21.0	21.8	22 6	23.4	24.2	24.9
3	25 7	26.5	27 3	28.0	28.8	29.6	30.3	31.1	31.8	32.6
4	33.3	34.1	34.8	35.6	36.3	37.1	37.8	38.5	39.3	40.0
5	40.8	41.5	42.2	43.0	43.7	44.4	45.1	45.9	46.6	47.3
6	48.0	48.7	49.4	50.2	50.9	51.6	52.3	53.0	53.8	54.5
7	55.2	55 9	56.6	57.3	58.0	58.7	59.4	60.1	60 8	61.5
8	62.2	62.9	63.6	64.3	65.0	65.8	66.4	67.1	67.8	68.5
9	69.2	.....	.....	.....	.....	.....	.....	.....	.....	.....

All observers in the United States using anemometers similar in construction to those of the Signal Service will find the values in the above table much more accurate than those commonly used.

APPENDIX C.

TORNADO STATISTICS.

The characteristics of tornadoes, the general meteorological conditions favorable to their formation, and statistics relative to their frequency, place of occurrence and essential details, have been made the subject of careful study and record by the Weather Bureau.

The reports of Lieutenant J. P. Finley, published as Professional Papers of the Signal Service No. VII and No. XVI, give the results of his researches relative to tornadoes prior to 1881, and a special study made of those occurring in the year 1884. The data for tornadoes, 1889–1896, have been recently compiled under direction of Mr. Willis L. Moore, Chief of the Weather Bureau, and are published in the annual data volume of the Bureau for 1896. These reports treat the subject in great detail, and the following facts have been abstracted from them:

The earlier records, which are necessarily incomplete, show that there were at least 580 tornadoes prior to 1881, and that of this number 505 occurred in the period of eight years, from 1874 to 1881, and 135 were unusually destructive. In the year 1884 there were 180 tornadoes. In the period of eight years, 1889–1896, there were 368 tornadoes occurring on 207 days; of these storms 24 were very destructive. "More than 90% of the property loss of the eight years fell on these 24 days. The remaining 10% was distributed throughout 183 days in which tornadoes of greater or less violence occurred. The great tornadoes of the past eight years have averaged about three per annum. Lists of very destructive storms for the 18 years previous to 1889 show an average of three per annum."

The number and the violence of tornadoes bear no definite relation to their destructive effects, as the latter are largely incidental to the place of occurrence. Of the $24 000 000 property loss by tornadoes during the past 8 years, $12 000 000 is chargeable to less than a half hour's destruction in St. Louis, Mo., and East St. Louis, Ill., on May 27th, 1896, and over $2 000 000 to the destruction in Louisville, Ky., on March 27th, 1890.

DISCUSSION.

Mr. Knap. JOSEPH M. KNAP, M. Am. Soc. C. E.—While it may be true that lightning never strikes twice in the same place, the same cannot be said of tornadoes, for in 1871, when the speaker was in St. Louis, a tornado passed over nearly the same course as that described in the paper. A locomotive weighing 40 to 50 tons was overturned, and it was roughly estimated that no known pressure of the wind could have done this; apparently the only explanation of the occurrence was the formation of a partial vacuum. A heavy sleeping car was also carried some 75 ft. and overturned. Fortunately, the section of the city most affected by the recent tornado was not built up at the time first mentioned, and the bridge over the Mississippi, although planned, had not been constructed.

Mr. Morison. GEORGE S. MORISON, Past-President Am. Soc. C. E.—Mr. Knap has done well in mentioning the earlier tornado, an account of which is given in Professor Woodward's history of the St. Louis Bridge. This earlier tornado possibly saved the bridge from being destroyed by the tornado of 1896, a very heavy wind truss having been added to the original design, as the result of the observations made on the effects of the earlier tornado.

The speaker was in Kansas City on his way to St. Louis when the tornado of 1896 took place. It was a very hot day, and suddenly late in the afternoon the temperature fell very rapidly; the general conditions indicated a violent storm, but no trouble occurred in that neighborhood. This is mentioned simply to show that the disturbing meteorological conditions were felt over a considerable distance. The speaker left Kansas City at 20.45, and when 50 miles out heard of the trouble at St. Louis. He reached St. Louis about 24 hours after the tornado; on the following day he walked through the devastated district. He was impressed with the fact that there was a great deal of destruction, and that there was a great deal to learn, but he felt that he could understand comparatively little. The larger part of the buildings destroyed were of flimsy construction; if the brick walls had been 4 ins. thicker, had been laid up with cement instead of lime mortar, and the millinery of mansard roofs, and such other decorations, had been left out, the destruction would probably not have been one-tenth of what it actually was. In one building, which was pretty thoroughly destroyed, the partition walls, about 20 ft. apart, were only 4 ins. thick; such a destruction proves nothing; it was unfortunate for the people who lived in this building, but it was the duty of these walls to give away under very moderate strains. However, buildings were destroyed which were fairly well built, and there were

evidences of a wind pressure which might have been disastrous even to the best built work. Mr. Morison.

The Burlington Freight Station was built by the speaker. The roof was of light iron construction, with a wooden covering of rafters and boards. The light steel trusses were riveted to a series of heavy columns which were proportioned to resist wind pressure in both directions, and were anchored to masonry foundations which were carried down to rock, less care being taken with the foundations of the other parts of the building. Every part of the iron work which was dependent on these columns stood perfectly and was not injured; the trusses, which were very light but adapted to withstand equally upward or downward forces, were unhurt. Observations at that time seemed to show conclusively that a roof should be designed to resist an upward pressure almost or quite equal to the downward pressure which it is customary to provide for. The new St. Louis Union Depot was entirely uninjured, though the top of an elevator near by was taken off. The tornado in fact did not strike the depot; the roof of the car shed of that depot is designed to carry weight, but not fitted to resist an upward pressure; if the tornado had struck it, it would probably have been destroyed.

The speaker saw nothing which seemed a proof that a vacuum existed in the center of the tornado. There were a number of houses in which the pressed brick fronts were taken off, but the vacuum caused by wind passing around sharp corners might have been enough to provide for this.

CORRESPONDENCE.

Mr. Johnson. J. B. JOHNSON, M. Am. Soc. C. E.—As the writer's home was in the path of the storm and was partially destroyed, he had abundant opportunity to study its effect and has tried to reason as to the operating causes. In general he can only say that he thinks the author has come as near to a rational explanation of these causes, and the method of their manifestation, as it is possible to reach with the present knowledge of the subject. By common consent among the St. Louis engineers, the author was urged to write an account of the great tornado for the Society, as being one in whom they would have implicit confidence, both as to his facts and as to his deductions from them. The writer, therefore, commends this paper as including about all that can now be said with profit to engineers and architects, on the St. Louis tornado, and the lessons to be learned from it in the matter of structural designing. The partial vacuum produced by high winds over roofs and on the leeward side of buildings, together with the pressure inside of buildings produced by the universal breaking in of windows on the windward sides, would seem sufficient to explain nearly all the lifting of roofs and the outward falling of walls in the St. Louis tornado. The explosion theory, so commonly spoken of, does not seem necessary to explain the phenomena, and as this requires an extremely sudden reduction of pressure to become effective, the writer is inclined to discredit it as a generally operating cause.

Some important rules of practice, therefore, in the design of buildings would seem to be :

First.—Roofs and roof trusses should be designed to resist an upward (internal) force of about 10 lbs. per square foot over and above the weight of the roof itself, and they should be anchored to the walls strongly enough to resist this lifting tendency.

Second.—Side walls should be well tied to the floor and partition systems, so as to resist those internal wind pressures resulting from the breaking of windows on the windward sides of buildings.

If these two rules had been followed in the construction of the 8 000 buildings which were partially wrecked in St. Louis on May 27th, 1896, the writer believes a large proportion of them would have escaped with little more loss than that resulting from broken windows and fallen chimneys.

Mr. Eayrs. N. W. EAYRS, M. Am. Soc. C. E.—The tornado which forms the subject of the paper followed almost the same path as that of March 8th, 1871, which occurred during the construction of the bridge. The earlier tornado was much more severe than the recent one, as several empty freight cars were blown through the air for several hundred

yards, and a locomotive of the Wabash Railroad was lifted bodily from the track and thrown upon its back in the ditch several feet distant from the rails. It was in consequence of the destruction wrought by this tornado that Captain Eads modified the wind bracing on the Eads Bridge, substituting for the wooden structure originally designed a horizontal steel truss 54 ft. wide. The wisdom of this change was shown by the recent storm, as the bridge was not damaged seriously, although there were evidences that it was under very severe strain. Mr. Eayrs

In examining the buildings damaged by the tornado of last year, the writer was particularly impressed by the poor character of material and workmanship revealed. Even the masonry of the east arcade of the St. Louis Bridge, which had the appearance of great solidity, proved not to be what would now be considered first-class work. The principal defect in this work appeared in the joints, which were made of mortar in which, apparently, lime predominated; in some joints, moreover, trowel marks were visible, indicating that the mortar had partially set before the stone was placed on its bed.

In almost every brick building examined by the writer, the mortar was found to be of inferior quality and the joints only partially filled. In many instances the pressed brick fronts of the more modern and expensive houses were stripped from the backing, peeling off like a sheet of veneer, with no bond whatever between the face and the backing.

As an illustration of what well-built brick masonry can stand, even when situated in the vortex of the tornado, the two towers which flank the east end of the east arcade may be cited. One forms the northeast corner, and the other the southeast corner, of the arcade. The former lost only the roof, one floor and the windows, the walls being uninjured; the latter, which is shown in Plate III, Fig. 2, was injured by the fall of a heavy iron smokestack, which split the walls of the two upper stories. The towers are 20 x 30 ft. and 80 ft. high; the walls are 36 ins. thick at the base diminishing to 18 ins. in the two upper stories, and are built of hard burned brick laid in Louisville cement, with every joint flushed.

In computing the wind pressure required to overcome the stability of the walls of the east arcade, the author has proceeded on two assumptions, neither of which, in the writer's opinion, fully satisfies the conditions. The deck was undoubtedly lifted first, and thus produced a thrust upon the south wall, throwing it over. This wall carried with it the cross-girders, which, being fastened to the coping of the north wall, dragged it over. It will be noticed, by referring to the dimensions given in the paper, that the overhang of the coping of the south wall threw the center of gravity near the outer face, a position of least stability; and under this condition a wall 13 ft. high, and but $2\frac{1}{2}$ ft. thick, with poor cement in the joints, would be overthrown by a comparatively

Mr. Eayrs. slight thrust at the top. That there was a very strong upward component of the wind at this point, is shown by the manner in which the deck on the spans was stripped, and by the cracks which appeared in the thick paint skin at the junction of the main tubes with the couplings. The longitudinal girder, referred to on page 230. was evidently lifted bodily at least 3½ ft. vertically, and this disturbance of the deck might of itself throw down the south wall. It seems to the writer, therefore, that it is somewhat hasty to assume that there must have been a wind pressure of at least 60 lbs. per square foot against the wall.

The bridge was evidently in the vortex of the tornado, for the gyratory motion of the air was shown by the position of the débris. While the wreckage was mostly carried to the southeast, some of it was carried northeast. The smokestack standing on the north side of the east arcade was blown northeast, and two panels of fence, 12 ft. long, from the center of the bridge, with 7 x 16-in. stringers attached, were carried about 800 ft. northeast of their original position.

One feature of the general destruction particularly noticeable was that walls generally fell outward, a phenomenon which has been noted in previous tornadoes, and to explain which various theories have been advanced. In all explanations which have come to the writer's notice, one important fact has been generally overlooked. By far the greatest damage is done to dwellings, and to those of an inferior type ; this is shown conclusively by Table No. 1 of the paper. In this class of structures, the floor beams of the different stories and the ends of the rafters are not fastened at all to the walls, and it consequently takes less pressure from within to force the wall outward than would be required to force the same wall inward ; the floor beams act as struts to prevent the wall from falling inward. It is only natural, therefore, that the walls should fall outward.

Undoubtedly the walls are forced outward by a difference of pressure between the air within the building and outside, but, in the writer's opinion, this difference of pressure is caused not by the existence of a partial vacuum outside the building nor by suction, but by the air which is forced into the building by the violent wind. To explain the phenomenon noted by the existence of a partial vacuum outside, it would be necessary to suppose the difference in pressure to take place instantaneously. The instance cited of the low aneroid reading at Lafayette Park, which was in the center of the track of the storm, and therefore in a position where the vacuum would have the greatest effect, militates against the vacuum theory, since the destruction of the house did not occur until some minutes after the low reading was noticed. As the progressive motion of the storm was about 36 miles per hour, as noted by Mr. Frankenfield, there would be sufficient time for the pressure within and without any building to be equalized.

It would seem more reasonable to suppose that the violent inrush of air towards the center of the tornado condenses the air in the portion of the house most exposed to the wind, and thus forces the walls out. In this tornado the duration of the extremely violent gusts was sufficient to condense the air to quite an appreciable degree. The stripping of patches of slate or tile from roofs, as well as the peeling of brick or stone facing from the walls of the houses, may be readily explained in this manner, the air being driven under the slate or into the interstices of partially filled joints in brickwork, with sufficient force to tear the covering loose. Mr. Eayrs.

It does not seem to the writer necessary, as far as his observation of the effects of the tornado under discussion warrants, to assume the existence of a suction to account for the phenomena. Whatever laboratory experiments may show, the action of suction, if it exists, is due solely to a difference in pressure between the windward and leeward sides of the object. There were many instances of walls being undoubtedly blown out on the leeward side by the wind entering the building from the windward side, and as this simple explanation holds good in so many cases, it would seem reasonable that it should hold good in all.

The most instructive part of the paper is the discussion of the probable effect of tornadoes on high buildings. The accuracy of the author's reasoning and computations can only be tested by another tornado, an experiment which those who have been through such an experience are not anxious to see made. The distinction made by the author between the skeleton and the cage types of such structures is a good one. In view of the strength of riveted connections and their superiority over bolted connections, the common type hitherto, as shown in the wreck of the factory building illustrated in Plates VI, and VII, it would seem scarcely credible that a well-designed cage structure, with proper wind bracing and all connections riveted, could utterly collapse. The yielding of the steel members and connections would probably be so gradual and so localized that the occupants of the building would have opportunity to escape.

A. A. Stuart, M. Am. Soc. C. E.—The subject of the paper is one of very great interest to the general public and to the profession, but to the engineer it possesses a specific scientific value, inasmuch as it establishes a new maximum for the intensity of wind pressure. Fortunately for mankind, the opportunity for witnessing such full-size tests to destruction seldom occurs, and even more rarely offers any means of so accurately gauging the actual energy of the moving mass of air. The writer is quite familiar with most of the structures described in the paper, and nothing short of their actual destruction by force of the wind would have induced him to believe they could be so destroyed. This fact makes him realize more fully the great Mr. Stuart.

Mr. Stuart. pressure of the wind than would the mere statement of its intensity in pounds per square foot.

The writer was in Louisville, Ky., within a few days after the tornado which passed over that city on March 27th, 1890, and inspected many of the structures which were then destroyed, but failed to observe anything which would give more than a general conception of the force of the wind.

The deductions made by the author as to the relative value of bolts and rivets, as used in fastening together various members in metallic structures, will be of much value to designers of such structures in correcting the theories of some and confirming those of others, but it is believed that the greatest good to the public growing out of the study of the paper will be realized in so changing many of the designs for tall buildings, now so common, as to adapt them to resist lateral forces better. Much has been said and written on this subject by those who have observed the entire absence of any provision for other than vertical forces, but apparently with few beneficial re-

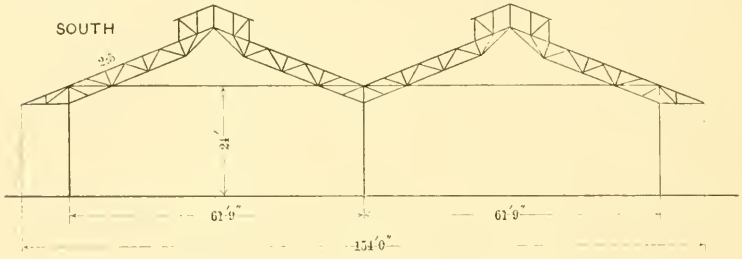

FIG. 20.

sults thus far. It is to be hoped, therefore, that the facts of the St. Louis tornado recorded by the author will induce a radical change in this respect, as the collapse of a tall office building in a large city would be a calamity now invited by many of the existing structures, but too horrible in the possible destruction of human life to contemplate without an effort to avoid its probability. A large percentage of the tall buildings now being constructed in the large cities derive their lateral stability almost wholly from the inertia of the mass of materials used in their construction, and the apt illustration of the pendulum given by the author very forcibly emphasizes how small this resistance is in fact.

Mr. Baird. HOWARD C. BAIRD, Jun. Am. Soc. C. E.—It became the writer's task some few years ago to examine an iron structure wrecked by the wind, and to find out what members could be used in rebuilding. A number of points was noted bearing directly on some of the conclusions mentioned in Section II of the paper.

This structure was the trainshed of a passenger station, and was destroyed by the Louisville tornado of 1890. It was of iron, all riveted,

and was about 340 ft. long and 154 ft. wide, supported on three lines of posts, with no side or end covering, thus allowing the air to blow freely underneath. A small portion at one end on the windward side was protected by the head house, then under construction. Mr. Baird.

The promptness with which the railroad company removed the wreck made it impossible to observe many points that might otherwise have been noticed, but such facts as the value of rivets in tension and the strength of riveted joints under severe shocks were clearly shown.

The tornado struck the south side of the shed, which fell by the posts failing in flexure directly below the knee braces and at the bases, in some cases being torn vertically from the bases, showing that the wind exerted some lifting force. The roof trusses were injured only when they fell on cars, and it is safe to say that had the shed been empty at the time, little or no harm would have come to the roof

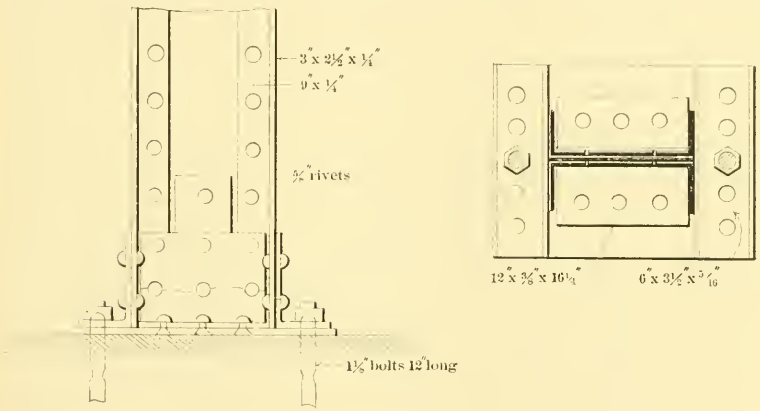

FIG. 21.

proper, even though it fell a matter of 20 ft., such was the strength of the riveted joints. Fig. 20 shows a cross-section of the shed, and Fig. 21 a detail of one of the post feet; Fig. 21 also shows how the connecting angles in tension ruptured while the ⅝-in. rivets held, and the base plate, together with the portions of these angles remained firmly fixed to the masonry, such was the holding power of the ordinary notched bolts. Although all bolts did not hold so well, the great majority did, but few pulling out or breaking in the thread.

The great difficulty in getting apart even the most severely injured joints, in which the rivets had to be cut out, shows clearly the truth of the author's fifth conclusion, that riveted joints "will stand, even under jar and shock, an excessive amount of abuse and distortion before actually separating into individual pieces," and that it applies to iron as well as steel.

Mr. Hazen. HENRY ALLEN HAZEN, Esq.—On the morning of May 27th, 1896, a general storm, with a depression in pressure at its center to 29.62 ins., was central in north central Kansas. This storm moved very rapidly in an east-northeast direction, reaching northwest Illinois in twelve hours, or with a velocity of about 40 miles per hour. The lowest pressure at the evening observation, 20 o'clock, was 29.56 ins., at Davenport, Ia. There were a great many thunder storms during the afternoon in the southeast quadrant of this general storm, but at only one place, St. Louis, did these assume serious violence. At this point (including East St. Louis) occurred the most severe tornado ever noted in this country, causing a loss of about 350 lives and $12 000 000 of property. The author has devoted earnest study to this tornado, and his work is to be commended. There are several points, however, in which he seems to have been tied down to pure theories advanced forty years ago, which have been somewhat modified by more recent studies. The actual tornado occurred, as nearly as can be determined, at 20.22 o'clock, and this point of time should be carefully noted. It has been shown that on all days when there is any tornado action the destructive storms have a motion from southwest to northeast, the first track beginning early in the afternoon and each successive track occurring later and farther toward the south. Thus at Higbee, Mo., the first track was noted at 15 o'clock, and the direction of the tornado was toward the northeast. Higbee is about 140 miles west northwest from St. Louis. At Mexico, Mo., 102 miles west-northwest of St. Louis, the track was toward the east, and the destruction occurred at 16.20 o'clock. There are some apparent exceptions to this rule, abundantly established by more than a score of different tornadoes, but in all these cases there has been confusion with the accompanying thunder storm. It would seem that in any general study of the problem it is necessary to take into account these peculiar swaths or rows of destruction gradually working to the south and southeast as the falling temperature of the evening draws on.

In nearly all descriptions of severe tornadoes which have occurred by daylight it has been noted that the inception of the violence was in the meeting of two clouds, one approaching from the northwest and the other from the southwest. This is a characteristic phenomenon of nearly all tornadoes, and merits most thorough study and analysis. It is evident that the phenomenon is a continuous one, and that the apparent meeting of the clouds at any one point is a mere incident or optical illusion, for the same clouds are seen all along the track for perhaps 100 miles.

All attempts at determining a whirl from the appearance of the funnel, or scattering of leaves, dust and debris in the funnel, were abandoned long ago for the reason that such action cannot be observed carefully when one is fleeing for safety. It is necessary to look to the

distribution of débris which can be studied at leisure after the tornado has passed. The writer has seen no map giving even an approximate idea of the distribution of débris at St. Louis, but there are many such maps for other severe tornadoes. These maps show a uniform distribution either in the direction of the track or inclined toward the center in nearly all cases. One of the best of such maps* was published by the Iowa State Weather Service in connection with the Pomeroy, Ia., tornado of July 6th, 1893. In this map on the north side of the track is shown débris pointing to the southeast or at right angles to the general track of the tornado. This is an extremely significant fact, and when it is learned that the débris from the northeast lies under that from the northwest it will be seen that the trees and timber must have been blown down by an earlier current from the northeast. It is not very difficult to see that the cloud, before mentioned, on the right of the track looking west, causes the first destruction, and afterward there is the general destruction in the main track. The writer thinks that the evidence of straight-line winds and lack of a definite whirl 500 or 600 ft. in diameter is complete in all cases where accurate maps of the débris have been published. Mr. Hazen.

There is a remarkable corroboration of this fact in observations or records at the Weather Bureau station in St. Louis. Very fortunately a fully equipped station was only about 1 mile to the north of the track, and the records there may be relied on. The winds had been strong all the afternoon and blowing from the southeast toward the general storm already described. Suddenly, between 18.10 and 18.15 o'clock, the wind blew from exactly the opposite direction, or from the northwest; this shift in direction was due to the tornado, and the indication is very plain that the wind was blowing clockwise, or around a high-pressure area. Between 18.20 and 18.25 o'clock the wind just as suddenly shifted into the northeast and continued, showing an outflow from the tornado. The writer regards this as the most significant fact in the tornado, not even equaled by the trace of pressure.

It is generally admitted that a tornado is an extreme development of a thunderstorm, and there are hundreds of barograph traces showing a rise in pressure in a thunderstorm. Now, how can this be reconciled with a number of barograph traces showing a sudden fall in tornadoes? The best of these is perhaps the one at Paris, given by the author, in which there was a fall of 0.2 in. in the center of the tornado. At St. Louis the fall was about the same, though in this case nearly 1 mile from the center. In the tornado at St. Louis on January 12th, 1890, a barograph trace is shown which had no fall, but a sudden rise. In the Louisville tornado, March 27th, 1890, a barograph at Owensboro, Ky., 7 000 ft. from the track, showed a sudden

* See "The Mechanism of a Tornado," by the writer.

Mr. Hazen. drop and rise, while the same storm, or an offshot, at Cincinnati, O., gave a rather sudden rise. It has been thought by some that a sudden gust of wind would tend to draw the air out of a room by the chimney and cracks in doors and this might cause the sudden fall noted. One thing is very certain, great caution must be exercised in accepting any theory as to a sudden diminution of pressure in a tornado, or that this is anything more than an incident in its manifestation. If there is this tremendous fall in pressure, what is to become of the winds which are supposed to be blowing at 100 or 150 miles per hour toward the center? It seems as though a funnel, 600 or 700 ft. in diameter, would not require more than a few seconds to be filled full and running over. The author well shows that the force of the wind blowing so as to form a partial vacuum on the side of a house would be sufficient to carry out the wall, and this has been demonstrated again and again previously. It is commonly stated that it takes two or three minutes for a tornado to pass any given point, and in that time the change in pressure could be equalized inside and outside of a house, and indeed this is what the author shows.

The time has not come yet to begin a positive statement as to the forces acting in a tornado. It is impossible to conceive of a partial vacuum moving along the earth which does not have a violent and rather uniform wind blowing toward it or else counterclockwise. Now, in hundreds of cases it has been shown that of two objects standing side by side in the center of a tornado track, for example, a full and an empty barrel, the heavy barrel has been taken and the other left. The author gives a similar instance. Such an occurrence as that is impossible in a steady wind 300 or 400 ft. wide.

The estimates of possible wind pressures needed to destroy a building or do damage are to be accepted with great caution. It is certain that estimates giving 1 000 or 1 500 miles per hour are entirely erroneous, though it seems as if the author's estimates are somewhat too small. One of the best estimates, perhaps, is in the blowing off of a monument from its pedestal at Wallingford, Conn., August 9th, 1878, in which a wind of 260 miles per hour was computed.

Mr. Nipher. FRANCIS E. NIPHER, Esq.*—In calling attention to the possibilities of damage to large buildings from wind, the author renders a great service to the profession, and the writer most earnestly commends his thoughtful paper. His warning that wind pressures of a very serious kind must not be forgotten is one that cannot be safely ignored, but immediately the question arises as to what pressures must be expected, and how they are distributed over a large building. It is fair to say that present knowledge on one of these subjects is very imperfect. The author has been unusually successful in his studies of the ruins at St. Louis. Such information as he has collected should

* Professor of Physics, Washington University, St. Louis, Mo.

be supplemented by measurement of wind pressures on high buildings during severe winds. Such measurements have not been made thus far, because there was no practicable method of making them. Mr. Nipher.

It might seem that an open tube might be projected through a shutter on the windward side of a house, from which a connecting tube might lead the external pressure to a water-gauge within. This would be an application of the Pitot tube to determine wind pressures. This was the method used by Irminger in the experiments to which the author refers. This method will serve perfectly if the mouth of the collecting tube faces the wind. Such wind-gauges are much used in England in connection with wind vanes, which direct the tube to the wind, but when the axis of such a pressure tube makes an angle with the wind, the action becomes very complicated. Such a tube, projecting through a wall with which its mouth is flush, shows, as Irminger found, a suction when the wind strikes it at an oblique angle. This does not mean, as Irminger concludes, that the air pressure against the wall is less than atmospheric pressure. It means that the tube is partially exhausted by an action which is utilized in the atomizer. This atomizer action affects all of Irminger's work which the author describes, and the results are therefore not directly applicable to a case of simple wind pressure.

A tube 1 in. in diameter and 1½ ins. long, made of thin metal, having one end closed by a perforated bottom from which a ¼-in. connecting tube of rubber is led to a water-gauge, will measure wind pressure very accurately if its mouth be held accurately to the wind. The tube of the water-gauge should be inclined so that the rise is 4 or 5 in 100, in order to increase its sensitiveness. The cistern should be large enough, so that there is a fall of not over 1 for a rise of 100 along the gauge tube. If wind velocities are measured in centimeters per second, and pressures are in dynes per square centimeter, then

$$P = 0.5\ d\ V^2$$

where d = the density of the air in grams per cubic centimeter. At ordinary temperatures and pressures, $d = 0.0012$. If velocities are in miles per hour, and pressures are in pounds per square feet the above equation becomes

$$P = 0.00258\ v^2.$$

The writer verified this formula by measurements on trains, and as a mean of over 2 000 measurements he found the value of the constant in the above equation to be 0.00251. This method of determination applies only to compression on the windward side of an obstacle. It wholly eliminates the rarefaction on the leeward side.

If the tube be turned to an angle with the wind, the gauge shows a diminished pressure, and when the angle is about 60° the pressure is zero. Connecting and disconnecting the pressure collector with the

Mr. Nipher. gauge shows then no effect on the gauge. If the angle be increased, a suction is shown. When the angle is 90°, and the wind is therefore blowing across the mouth of the tube, the pressure tube shows about 10% more of fall than the rise when the mouth of the tube faces the wind. If the angle be increased, the suction becomes less, and reaches a minimum when the tube trails in the wind. The fall of the column in the gauge is then about 37% of the rise when the mouth of the tube faces the wind. In any position where the angle exceeds 90°, the air within the tube is not directly compressed by the wind, since the mouth is shielded by the tube. It is then affected only by eddies, which curl around the edge of the tube, stirring up the air within and jostling it into the air current, which sweeps it away until the limit of exhaustion is reached.

When the deviation of the tube is less than 90°, a component of the wind velocity is effective in producing atomizer effects in the tube, but this component is not effective in producing pressure against a wall.

These considerations indicate the grounds on which objection must be made to Irminger's conclusions. The writer thinks it doubtful if suction effects are of much importance in a tornado. The walls of a building brace each other internally, and the evidence of collapse from internal rarefaction is wanting, so far as his observation extends. As a tornado approaches an isolated building, the side next to the whirl is the leeward side, and on the outside of the leeward wall the pressure is less than atmospheric pressure. A window fails on the windward side. Immediately the wind pressure on that side is transmitted through the rooms of the building with a velocity which is practically instantaneous. The pressures on the windward walls are then more nearly balanced than before the window broke, but the difference of pressure on the leeward wall is thus increased. Above the roof the wind is also acting on fire walls or chimneys on the leeward wall, and here most of the damage seems to begin. The leeward wall is the vulnerable point in an isolated dwelling house.

A moment later the tornado passes, and the windward wall becomes a leeward wall, and may suffer even greater damage because of the fact that it is more fully exposed by reason of damage to the opposite walls. It is in this way that the writer has explained the outward falling of walls in the various tornadoes which he has studied.

The author makes it very clear that local whirls must exist everywhere when a tornado passes over a city, and that these vortices must contribute to local effects, such as were generally observed in the St. Louis tornado.

If a tube pressure-collector, such as the writer has previously described, be exposed on the windward side of a building, surrounded by other buildings at various distances and having various heights, the water column of a pressure gauge connected with it behaves in a most

capricious way. As a gust of wind lasting for ten or fifteen seconds Mr. Nipher.
passes, the column rises and falls continually, responding to the atomizer effects of the shifting currents around the mouth of the tube, as well as to the changes in pressure of the air against the building. What is desired is the difference in the resulting pressure of the air on opposite sides of a wall or building. The wind compresses the air next to the building. Wind effects are not of interest, except so far as the wind compresses the air in contact with the building, which in turn exerts pressure against the building. The pressure within the building where the air is practically at rest, can be easily measured by a barometer, but if placed outside of the building and in contact with the wall, it will be exposed to the wind. It is itself an obstacle in the wind. The openings leading to its air spaces will be subject to atomizer effects, which will vary as these air spaces may open out to the windward or to the leeward of the barometer, and if the barometer is enclosed in a box or vessel to shelter it from the wind, the air spaces of the box are now in the uncertain condition which formerly applied only to those of the barometer.

The writer designed a pressure-collector which eliminates the atomizer effects and also the compression and rarefaction effects due to itself. It consists of two thin steel disks 4 ins. in diameter, such as are used in small circular saws. Each disk is ground on one side to a knife edge, so that when their unground sides are put together, the circular edge is sharp. Thin brass plates, also ground to knife edges, cover the central holes of the disks, and through these plates passes a screw which clamps the disks together. The head of the screw is soldered in, to make a tight joint. The opposite plate has a brass tube soldered to it, and the brass plate within the tube is perforated, so that the air within the tube communicates with the thin sheet of air between the knife-edge saw-disks. These disks are separated by a layer of permeable material, consisting of six to twelve layers of brass wire cloth, having 130 wires to the lineal inch. This layer of wire cloth must extend beyond the steel disks $\frac{1}{2}$ in. all around, and the edges are bound together in an over-seam by means of thin German silver wire. The thickness of a layer of six sheets of such wire cloth is 0.047 in.

The tube of this disk-collector is connected with the pressure gauge. The layer of wire cloth transmits pressures perfectly, but cuts off currents of air from the mouth of the tube which pierces one of the disks. Atomizer effects are thus prevented. The disk-collector is presented edgewise to the wind by holding it flat against the building, which it should not quite touch. The slight compression on the windward edge of the wire bundle is dissipated before reaching the steel disks, and the same is true of the rarefaction on its leeward edge. In a howling wind, every momentary change in the pitch of the sound is

Mr. Nipher. instantly seen as a rise or fall in the water column. A rise in pitch is always accompanied by a rise in the column and *vice versa*.

The writer has tested this collector on trains with speeds up to 60 miles per hour. The disk was held out of the window on a cylindrical rod provided with a graduated circle. Setting the disk edgewise in the wind and making connection with the water-gauge in the car, a difference of pressure will usually be shown. If the gauge is in the rear of the car, and windows and ventilators be opened at each end of the car, this difference in pressure disappears, just as it does when similar experiments are made in a house with an ordinary wind. The disk-collector is then cleaving the air at a speed of 50 or 60 miles per hour, but this wind does not affect the pressure-gauge. If the hand be placed just back of the disk, the air in front of the hand will be compressed, and the result is at once shown by a rise in the water column. In fact this device is wholly unaffected by wind, but responds instantly to a change in pressure of the air in which the disk-collector is placed.

The writer found, also, contrary to his expectations, that when held in any other than an edgewise position, the instrument gave practically the same results.

It is probable that the size of the disk-collector can be reduced to a diameter of 2 ins., and there is a possibility that it can be reduced to 1 in. This would be desirable in the study of the differences of pressure around the members of a truss.

Mr. Baier. JULIUS BAIER, Assoc. M. Am. Soc. C. E.—As the primary object of the study of the work of the tornado was to determine the intensity of the wind pressure exerted, the question raised by Mr. Eayrs as to the conclusion reached by the author in reference to the failure of the arcade of the Eads Bridge calls for some comment.

The objections advanced are: first, that the structure did not fail along the lines on which its stability was determined; second, that the estimate of 60 lbs. per square foot as the minimum intensity of the wind pressure is a hasty assumption.

It was not the intention of the author to advance any detailed explanation as to the exact manner in which the arcade was destroyed. With the incessant and violent changes, both in velocity and direction which are always present whenever the air is in motion, any deduction as to the sequence of action in the work of destruction is clearly impossible. If it is known, however, that a structure was overturned solely by the action of the wind, and if, further, it is possible to make a definite estimate of its stability along the line of least resistance, then surely the means are at hand to determine with certainty the least pressure which must have been exerted by the wind over the area in question, whatever the actual pressure or its distribution or its line of action may have been.

Such were the conditions in the case of the east arcade of the Eads

Bridge. All details as to the dimensions of the structure, the weight of the materials and details of construction were obtained by the author from a careful personal inspection, and were presented in the paper in minute detail, in order to allow any reader to make an independent analysis if the conclusion drawn by the author seemed unreasonable. The masonry was built of blocks of stone the full width of the wall, and no account was taken of the tension value of the mortar in the joints, the stability against overturning being estimated for the dead weight only, as in the case of a dry wall. The computations are of the most elementary nature, and introduce no uncertainties. The results are dependent solely on the accuracy of the data. Mr. Baier.

The author, therefore, wishes to emphasize the claim that the final deduction of 60 lbs. per square foot as the minimum intensity of pressure which must have been exerted by the wind at the east arcade of the Eads Bridge, is in no way a hasty assumption, but must be accepted as a fact, unless it is disproved by some actual computation made in conformity with the essential facts in the case.

The assumption made by Mr. Eayrs that the decking alone was lifted first is clearly in error, since each girder was secured to the decking by 12 bolts, and simply rested in turn on the side walls, unsecured by any anchorage whatever. All indications show clearly that the girders were carried away with the decking, and the instance mentioned in the discussion, of the longitudinal girder raised $3\frac{1}{2}$ ft. vertically, can be explained in no other rational way than that the girder hung to the decking and was raised with it. As the weight of the floor varied from 59 lbs. to 70 lbs. per square foot, the lifting of the same would in itself require an oblique upward wind with an intensity of pressure much greater than 60 lbs. per square foot.

Beyond the immediate effects of wind pressure on structural work, the subject of tornadoes belongs rather to the province of the meteorologist than the engineer. A brief explanation of the mechanism and action of the tornado has, however, been presented in the paper, partly in explanation of the general conditions attending such storms and partly to bring out more clearly the limitations of the fall in pressure or the partial vacuum formed at the center of the storm and of the very high velocities of the wind, several hundred miles per hour, which are frequently referred to by meteorologists, and tend to create the impression that such storms are irresistible. While these extreme conditions may exist over a limited area in the higher altitudes of a tornado, it is more probable that the destructive pressures exerted near the surface are in the main those arising from the inflowing air currents and are not greater than can be readily provided against in engineering structures.

In stating the theory of the tornado the author had no intention of presenting any views or theories of his own, but rather to restate the

Mr. Baier. explanation, mathematically developed by Ferrel along lines originally formulated by Espy some fifty years ago. The results of Professor Ferrel's works have gained for him a world-wide reputation, and his theories are almost universally accepted by students of dynamic meteorology. The exceptions which Mr. Hazen has taken to these theories are: first, as to the existence of any whirl in the tornado; and, second, as to the existence of an inward rather than an outward flow of air. The conditions in St. Louis certainly confirm the theories of Professor Ferrel. The barometric records indicated a severe local fall in pressure which could only have been occasioned by a whirl; the inflow of lateral air currents from all sides into the general storm center was established conclusively by the many evidences of this characteristic action. Mr. Hazen further bases some of his deductions on the assumption of "a steady wind 300 or 400 ft. wide," whereas it is now well known that air moves in a tumultuous mass continually subject to the most extreme and irregular fluctuations in velocity. The wind in such storms assumes a violently agitated and turbulent condition as much unlike the steady current in which it is often assumed to flow as the Niagara whirlpool is unlike a quiet stream of water; and it is hardly necessary to add that any formulas deduced from fair-weather experiments are about as applicable to severe storm conditions as the ordinary hydraulic formulas would be in the case of the whirlpool.

While the explanation advanced by Professor Nipher as to the atomizer effect of oblique air currents may partially account for some of the results obtained by Irminger and affect the relative values found by him for direct pressure and for suction, it does not in any way change his general conclusions as to the reduction of the atmospheric pressure present on the leeward side of obstacles exposed to the wind.

The large percentage of the total force of the wind which is due to this cause is moreover indicated by other results. The experiments made by Professor Marvin, with pressure boards, to determine the total effect of the wind show that the relation between velocity in miles per hour and pressure in pounds per square foot is expressed by the formula $p = 0.0040\ v^2$.

The results recently obtained by Professor Nipher show, as previously found by other experimenters, that the effect of compression on the windward side only is almost exactly in accord with theoretical values and is $p' = 0.0025\ v^2$. A simple subtraction gives $p'' = 0.0015\ v^2$, and this last equation must therefore represent the force due solely to the rarefaction on the leeward side. These coefficients give ratios of 25 to 40 or 62% for direct pressure, and 15 to 40 or 38% for suction, values that do not differ from those found by Irminger by more than the various formulas for total wind pressure differ from each other. Since the effect due to compression on the windward side is expressed by a

constant coefficient it would seem that the wide variation in the values of the coefficients expressing the total wind pressure must be caused mainly by the variation in that proportionate part which is due to this rarefaction. Mr. Baier.

That the outward or lifting force due to this suction effect is present in wind storms can be seen occasionally by such examples as the partially destroyed church shown on Plate III, Fig. 1, selected from a number of such instances that came under the notice of the author, to illustrate this action. In this case the entire roof was carried away while the weaker and lighter ceiling was only partially broken. If the damage had been caused merely by the wind blowing into and being compressed within the building, the light ceiling would have been entirely destroyed before the roof could have been lifted.

The pressure collector designed and perfected by Professor Nipher is an exceedingly ingenious and valuable device, and will undoubtedly find a varied application in pressure measurements. Unfortunately, the determination by experiment as suggested of the actual intensity and distribution of wind pressures against structural work is involved in difficulties entirely beyond control, due largely to the complex and variable nature of the wind itself and to the infrequent opportunities to make such experiments at high velocities. The wide range of values obtained by many experimenters on so simple a structural element as a square plate further suggests the indefinite results that must be expected when dealing with the more intricate surfaces of actual structural work.

The engineer is mainly interested in a measure of the intensity of the maximum wind pressures which occur in violent storms. Such knowledge can be obtained more definitely from a critical analysis of the actual total destructive work of the wind as manifested from time to time than from deductions based on the partially known elements of the very complex action of the wind.

The accumulated data afforded by such catastrophes as that described in the paper, when properly interpreted, must ultimately be accepted as a guide to the rational design of important structures exposed to the action of the wind.

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A STUDY IN THE DESIGNING AND CONSTRUCTION OF ELEVATED RAILROADS, WITH SPECIAL REFERENCE TO THE NORTHWESTERN ELEVATED RAILROAD AND THE UNION LOOP ELEVATED RAILROAD OF CHICAGO, ILL.

By J. A. L. WADDELL, M. Am. Soc. C. E.

PRESENTED FEBRUARY 17TH, 1897.

WITH DISCUSSION.

The principal object of this paper is to bring out an exhaustive discussion on the subject of the designing and construction of elevated railroads.

For some years the author had felt that the methods in vogue for constructing elevated railroads were radically wrong, so when he assumed the duties of Consulting Engineer to the Northwestern and Lake Street Elevated Railroads, in July, 1894, he began an elaborate investigation concerning the best way to design, manufacture, and build such structures. In reporting on some proposed plans for the

Wabash Avenue Extension of the Lake Street line, which forms one side of the Union Elevated Loop Railway, he gave the following list of essentials of elevated railroad construction :

First. Loads.—The loads to be considered are these:

A. Live load.

B. Dead load.

C. Thrust of braked trains, or traction load.

D. Wind load, or in reality an assumed transverse load to provide for sway of trains.

E. Centrifugal loads on curves.

Second.—Designing.

F. Longitudinal girders should have sufficient sectional areas, and should be properly detailed.

G. A proper system of bracing between contiguous longitudinal girders should be provided.

H. There should be a proper connection of longitudinal girders to cross-girders.

I. There should be adequate means of transmitting the thrust of braked trains from longitudinal girders to columns without overstraining the cross-girders.

J. The cross-girders should be properly designed in respect to both sectional areas and deta ls.

K. There should be a proper connection of cross-girders to columns to provide for transmission of both longitudinal and transverse horizontal loads.

L. The sections of the columns should be properly designed to provide sufficient strength to resist direct load, bending from longitudinal thrust, bending from transverse thrust, and, on curves, bending from centrifugal loads.

M. There should be a proper anchorage at the foot of each column to make the latter, as far as strength and rigidity are concerned, absolutely continuous with the pedestal.

N. There should be an adequate wooden floor, effectively attached to the metalwork of the superstructure.

O. The general construction of the entire structure should be as economical as practicable in respect to both quantities of materials and facility in erection, due respect being paid to the more important requirements affecting strength and rigidity.

P. The æsthetics of the design should be considered as much as possible without involving extravagant expenditure therefor.

This list of requirements will be referred to later on in commenting upon the details of existing American elevated railroads.

The immediate prosecution of the Lake Street Elevated work was a fortunate circumstance, as far as the investigations for the Northwestern Elevated were concerned, for it gave the author an opportunity to make certain experiments and researches which he might otherwise not have had, notably in the lines of bearing capacity of Chicago soil, details of structure occupying streets, and cold-pressed threads for bolts.

In these investigations the author has received valuable assistance from Charles V. Weston, Esq., who holds the position of Chief Engineer on the Northwestern Elevated, the Union Loop, and the Lake Street Elevated Railroads, and from Samuel M. Rowe, M. Am. Soc. C. E., who was retained temporarily to aid in the preliminary work.

The design of the Wabash Avenue Extension will be referred to later on; meanwhile the investigations for the Northwestern Elevated will be taken up in their consecutive order.

Before proceeding with these, however, it will be well to give a short description of the road. It starts as a double-track structure from the Wabash Avenue Extension of the Lake Street Elevated at the corner of Fifth Avenue and Lake Street, runs north across the Wells Street Bridge to Michigan Street; thence west to Franklin Street; thence north to Chicago Avenue, where it expands into a four-track structure (leaving the street and running into private property), whence it continues in a northerly and westerly direction to a point on Wilson Avenue between Evanston Avenue and the Chicago, Milwaukee and St. Paul Railway tracks, making the total length of line a little more than 6½ miles, of which all but 1 mile is four-track structure.

I.—Medium Steel *versus* Soft Steel.

At the outset it was necessary to determine whether it is more economical to use unreamed soft steel at a low intensity of working stress, or reamed medium steel at a higher intensity. This question was quickly settled in favor of the medium steel, which can be strained legitimately 10% higher than the soft steel, and costs prac-

tically the same per pound at the rolling mills. The ratio of weights of structure for designs in medium steel and soft steel is about as 93 is to 100, a saving of 7% in weight of metal in favor of the medium steel. Assuming the price of metal erected to be 3 cents per pound makes the saving in pound price 0.21 cent, while the cost of sub-punching and reaming varies from 0.1 to 0.2 cent per pound, according to the facilities of the bridge shop for doing such work. At present perhaps there is a slight difference in the pound prices erected of soft and medium steel in favor of the former, enough possibly to offset the net saving by reduced weight of the latter, so that, as far as the total cost is concerned, it is immaterial whether unreamed soft steel or reamed medium steel be adopted.

There is another point involved here, however, which is of far greater import than mere economy in cost of erected metal, viz., the proper matching of rivet holes in the component parts of built members. For several years the author has favored the sub-punching and reaming of all metal (although he has not always insisted thereon), not so much for the sake of the somewhat disputed benefit derived from removal of cracked metal by reaming, as for the greater certainty of obtaining properly matched rivet holes. His late investigations in this line, made by examining the shop work of the various bridge manufacturing companies of this country, both personally and through his assistant engineers and inspectors, confirm him to such an extent in this opinion that he is now prepared to make the following statement and to invite both criticism and denial thereof.

All structural metalwork, whether it be medium steel, soft steel, or even wrought iron, should be punched at least $\frac{1}{8}$ in. less than the diameter of the cold rivet and reamed to a diameter $\frac{1}{16}$ in. greater than same; and there is no bridge shop in existence which can turn out truly first-class work without sub-punching and reaming or drilling.

Even when the greatest care is taken in punching the metal of the component pieces of long members, many of the rivet holes will fail to match by as much as $\frac{1}{8}$ in., and the author has within a year or two seen $\frac{7}{8}$-in. rivet holes elongated to $1\frac{1}{4}$ ins., merely to admit the rivets. Where several component pieces containing badly matched rivet holes are placed together and a tapered flexible reamer is used to enlarge the hole sufficiently to admit the rivet, the latter cannot possibly fill completely the irregular hole, and, therefore, if left in the piece, can-

not act effectively. If condemned by the inspector on account of looseness, and then driven out, it will, on account of its crookedness, materially injure the metal about the hole and thus weaken the structure, perhaps doing more damage thereto than would the leaving in of the loose rivet.

The use of a tapered, flexibly connected reamer is all humbug, and is not true reaming at all, but merely a means of making it practicable to get the rivets through badly punched holes that assemble irregularly.

Real reaming can only be done with rigid reamers or drills that remain at all times at right angles to the surface reamed, and cut a cylindrical instead of a tapered hole. Such reamers as these are the only ones that ought to be employed on first-class metalwork, excepting, of course, in confined spaces where they cannot be used, and where the flexibly connected reamer must of necessity be employed.

The author knows well that these opinions are at variance with those of a majority of the manufacturers of structural steel, and it is on this account that he presents them so forcibly.

That many manufacturers are opposed to sub-punching and reaming was shown very clearly at the lettings of the contracts for the Wabash Avenue Extension of the Lake Street Elevated, and for the Northwestern Elevated, one manufacturer going so far as to make a difference of one-third of 1 cent per pound between reamed and unreamed work.

At these lettings good evidence was also given confirming a statement of the author, viz.: "It has been hitherto the general opinion that almost any kind of a structure in respect to design, quality of material and workmanship will suffice for an elevated railroad." One manufacturer remarked to the author in criticism of the plans and specifications submitted to bidders: "Why, your requirements in regard to details and workmanship are as rigid as if you were about to build a railroad bridge." The reply to this was, "Yes. I consider this structure to be just as important as any railroad bridge ever built."

And why should it not be just as important? Are not the live loads thereon more continuously applied, and is not the assumed maximum load very nearly reached many times per day? On these accounts, is it not even more important to make an elevated railroad absolutely

perfect in every detail of design and construction than it is to so make a railroad bridge?

The author is by no means alone in his opinion that nearly all the elevated railroads of this country will, in the not very distant future, have to be replaced, and mainly on account of faulty detailing. Of what the faulty detailing consists will be dealt with further on.

At this point the author wishes to call attention to a very reprehensible practice, which these lettings exemplified quite forcibly, viz., attempting to overthrow the engineer's plans and specifications submitted for tendering. In the case of the Wabash Avenue Extension letting a most determined but unsuccessful effort was made to alter the author's plans, so when the specifications for the Northwestern Elevated were drawn, the following clause was inserted with the permission of the president of the company:

"All work herein outlined is to be done in strict accordance with the following specifications, the accompanying plans, and such instructions as may be given from time to time by the company's engineers. Bidders are hereby warned that they will be held strictly to the spirit of these specifications, and that it will be bad policy for any one to bid with the expectation that concessions will be made after the contract is closed, in order that the work may be cheapened ; for while the company's engineers desire at all times to aid the contractors in every legitimate manner to do their work expeditiously and economically, at the same time they have given these plans and specifications the most thorough consideration, and know exactly what they need in respect to both design and quality of materials and workmanship. On this account bidders are respectfully requested not to complicate their tenders by putting in alternative bids based on proposed changes in either plans or specifications; because such alternative bids will not be considered."

The result of the insertion of this clause was rather amusing, for attempts were made to overthrow not only the plans, but the specifications also. However, but little difficulty was encountered by the engineers in throwing out all alternative bids; and the contract was let to parties who were willing to tender without suggesting changes in the plans and specifications submitted to the bidders.

Another question that came up at these lettings was that of using acid or basic open-hearth steel. Preference was given to the former in the specifications, but such evidence was submitted to the engineers as to convince them that the basic product can be made as satis-

factory as the acid, and at a trifle less cost; consequently, it was adopted. Since then, however, the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid; and that it may prove advisable in future specifications for basic medium steel to reduce the average ultimate stress limits from 64 000 lbs. to 61 000 lbs. per square inch.

It appears to the author that the general adoption of basic open-hearth steel is fast tending to the employment of soft steel for bridges. As far as short and medium spans are concerned, this is all right, but it is the opposite for long spans, especially for very long ones, where the dead load is the ruling factor in proportioning the members. Perhaps in the near future some alloy of steel, such as nickel steel, can be made cheaply enough to warrant its use for very long span bridges.

II—Weights and Dimensions of Motor Cars and Trailers.

After due deliberation it was decided to make both the motor cars and the trailers 40 ft. long out to out, and to carry each car on four

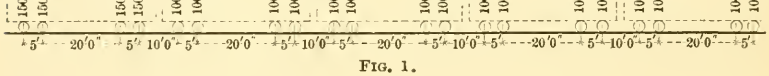


Fig. 1.

axles, the weight of a loaded motor car being 60 000 lbs., and that of a loaded trailer 40 000 lbs. The distribution of this live load is shown in Fig. 1.

III.—The Best and Cheapest Kind of Portland Cement to Adopt, and the Best Proportions for Concrete Made with Same.

This investigation was made by Samuel M. Rowe, M. Am. Soc. C. E. As a result thereof the author has modified his standard specifications for cement so as to read thus:

"All cement used in the work shall be Portland cement of the very best quality obtainable, equal in every particular to the best brands of American manufacture. It shall be ground so fine that at least ninety-seven (97) per cent. in weight will pass a standard sieve of five thousand (5 000) meshes to the square inch, and so that at least ninety (90) per cent. will pass a standard sieve of ten thousand (10 000) meshes to the square inch.

"When moulded neat into briquettes and exposed three (3) hours, or until set, in air and the remainder of twenty-four (24) hours in water,

it shall develop a tensile strength of from one hundred (100) to two hundred and fifty (250) pounds per square inch.

"When moulded neat into briquettes, and after exposure of one (1) day in air, and six (6) days in water, it shall develop a tensile strength of from two hundred and fifty (250) to five hundred (500) pounds per square inch; and after exposure of one (1) day in air, and twenty-seven (27) days in water, it shall develop a tensile strength of from four hundred (400) to six hundred (600) pounds per square inch.

"It shall be an eminently slow-setting cement, must develop its strength gradually, and must show no drop therein. When moulded into pats with thin edges, and either left on glass or not to set in water, said edges must show no signs of checking.

"Briquettes mixed in proportion (by weight) of one (1) part cement to three (3) parts sand, and kept one day in air and the remaining time in water, shall show a tensile strength of from one hundred (100) to one hundred and fifty (150) pounds per square inch after seven (7) days, and from one hundred and fifty (150) to two hundred and fifty (250) pounds per square inch after twenty-eight (28) days.

"In any case the cement adopted must be first approved by the Chief Engineer."

The proportions of Empire or Aalborg cements, which were the brands adopted for the Northwestern Elevated Railroad pedestals, used in making concrete, are:

One part by volume of cement.
Three parts by volume of sand.
Six parts by volume of graded broken stone.

Unless the stone be of several graded dimensions, so as to reduce the proportion of voids to a minimum, its proportion in the concrete should be reduced to five; for while these brands of cement will stand a three-to-one dose of sand, the resulting mortar will not fill completely all the voids in the stone at one, three and six, unless the grading of the stone be done very carefully, and unless the various sizes of stone be thoroughly mixed.

For concrete for bridge pier caissons, using these brands of cement, the author would recommend the following proportions:

One part by volume of cement.
Three parts by volume of sand.
Five parts by volume of broken stone.

In case, however, the concrete be deposited under water or in places where special strength and solidity are required, the proportions should be changed to one, two and four.

IV.—The Best and Cheapest Kind of Metal Paint to Adopt.

Mr. Rowe conducted this investigation also, but unfortunately was not able to complete his experiments. He has promised to give in his discussion his results as far as they go. It was decided to use for the Wabash Avenue Extension Eureka paint, and the National Paint Company's No. 31 for the Northwestern Elevated. In another structure, if the author could have his own way in respect to paint, he would give the metal a good coat of boiled linseed oil at the mills before it is exposed to the weather, one priming coat of Eureka paint at the shops, while the metalwork is still under shelter, and two coats of first-class iron oxide paint after erection.

V.—Prices of Timber F. O. B. Cars Chicago.

This investigation was made in order to determine what kind of timber to adopt, and whether it be advisable to specify all heart or a certain portion of sap, the result being that it was decided to use the best quality of long-leaf southern yellow pine entirely free from sap. This question of timber will be further treated in Section 12.

VI.—Best and Most Economical Span Lengths.

This question was investigated very exhaustively, considering every item of expense, including not only cost of metal in place, but also that of concrete, excavation, back-filling and pavement; also the possibility of expense for the moving of water pipes and other conduits. The investigation showed that for plate-girder construction through private property the economic span length is about 40 ft., while for construction in the street it varies from 47 to 50 ft., or even 3 or 4 ft. more in case of cross-girders spanning wide streets from curb to curb.

The theory of true economy in elevated railroad designing, as far as length of bays is concerned, is simply this: "The cost of the longitudinal girders should be, as nearly as may be, equal to the cost of the bents and their supporting pedestals, in case of doubt adopting the longer span."

VII.—Four-Column *versus* Two-Column Structures.

Detailed estimates of cost show that as far as economy is concerned there is but little, if any, difference between these two styles of bent.

Whether the total cost of the four-column bent will exceed that of the two-column one for a four-track structure depends upon the various schedule prices for metal, concrete, excavation, paving, etc., as well as upon the character of the soil. As there is no great difference in the cost of these two types of structure, and as the four-column bent is decidedly the more rigid of the two, it was adopted wherever practicable. Fig. 2 gives a general elevation and plan showing the steelwork. Cantilevering an entire train load beyond the exterior column of a two-column bent is not conducive to rigidity, but this is the only method that will bring the cost as low as that of the four-column bent.

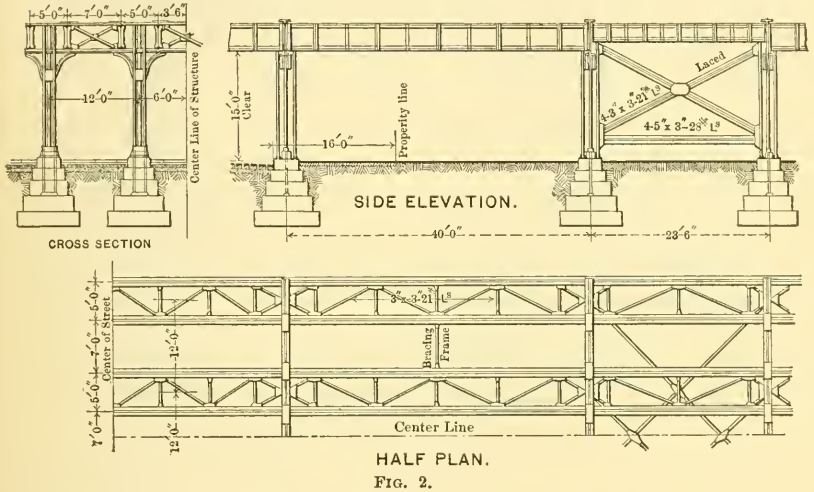


FIG. 2.

VIII.—BRACED TOWERS *versus* SOLITARY COLUMNS.

Where an elevated railroad occupies private property and crosses the streets by spanning from curb to curb, it is practicable to use braced towers and thus stiffen the structure and check vibration; and, moreover, this arrangement is very economical.

For the Northwestern Elevated, upon which it is proposed to run trains at a speed of 40 miles per hour on the inner tracks between the inter-track stations, which are situated about a mile apart, the consideration of the extra rigidity afforded by the braced towers is quite important. It was therefore decided to use both longitudinal and transverse sway bracing forming braced towers spaced about 150 ft. apart (or two towers per block), and to use the transverse sway brac-

ing on all bents on curves, wherever practicable. Fig. 3 gives the details of the longitudinal sway bracing for a 23½-ft. span.

Two only of the three spaces between columns are to have trans-

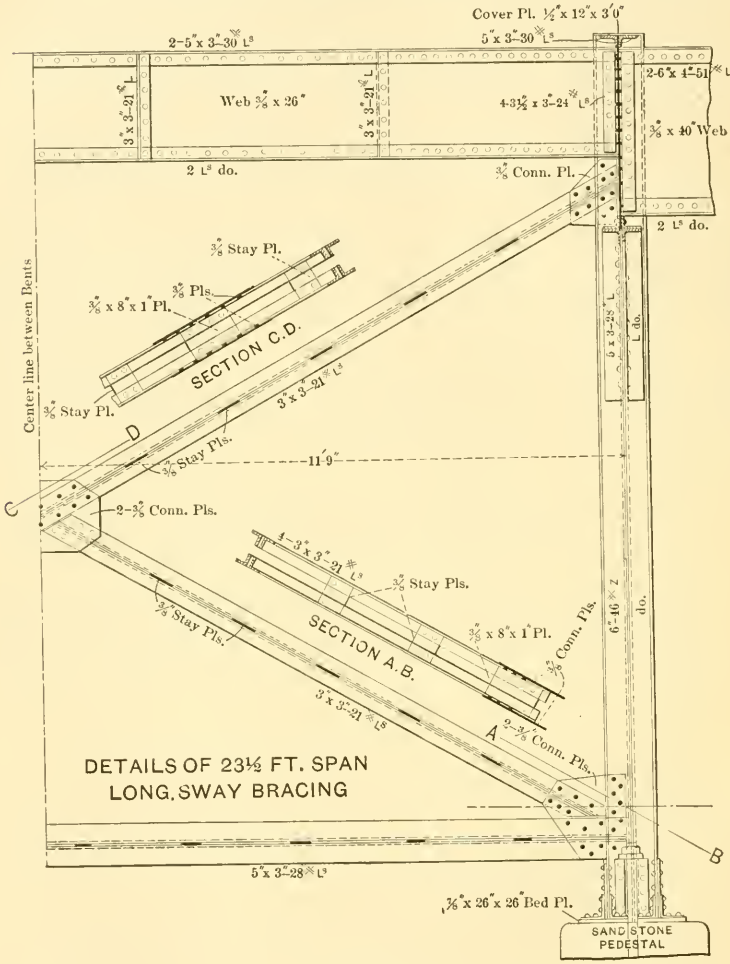


FIG. 3.

verse sway bracing, thus leaving a longitudinal passage-way for wagons at the center of the structure.

The saving in weight of metal per lineal foot of four-track structure on tangents by adopting braced towers instead of solitary columns was found to be about 140 lbs., or nearly 9% of the total weight.

IX.—The Best Weight and Dimensions of Track Rails.

After thorough investigation it was decided to adopt, as the best and most economical section, an 80-lb. rail, 5 ins. high, with vertical sides, and containing 45% of its metal in the head.

X.—Best Arrangement and Dimensions of the Wooden Floor.

The result of the investigation on this subject was, for longitudinal girders spaced 5 ft. centers, the adoption of 6 x 8-in. ties laid flat and spaced 14 ins. centers; 6 x 6-in. inner guards and 6 x 8-in. outer guards on edge, all guards being fastened by soft steel bolts with pressed threads, and connections to the metalwork being made by means of hook-bolts. Fig. 4 illustrates the track system.

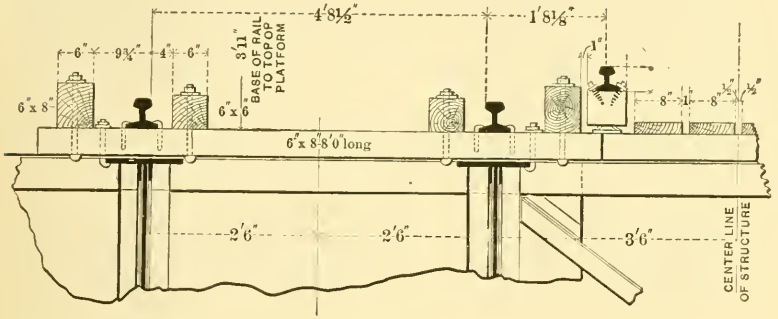


Fig. 4.

XI.—Collection of Data of Various Kinds Concerning Elevated Railroads.

The results of this investigation, made by the author and his assistants by examining the principal elevated roads of the East and those then in operation in Chicago, as far as the designing of the metalwork is concerned, amount simply to the accumulation of a great mass of information exemplifying "how not to do it."

Such negative data are, of course, useful; but, if a properly designed and constructed road in operation could have been examined, the information accumulated would have proved much more valuable.

Much useful information, however, was obtained upon such matters as track, stations, signals, etc., by the examination of existing elevated railroads.

XII.—Treated *versus* Untreated Timber for Tracks and Platforms.

After considerable investigation it was decided to preserve the timber by the vulcanizing process. The following extracts from the author's report to the company on this subject may be of interest.

"Unfortunately, the only vulcanizing works in this country are located in New York City; consequently, the freight rates on vulcanized timber delivered at Chicago are high, the average price for such timber as we need being about $32 per thousand delivered at site, while the untreated timber would cost only $18 per thousand. It will cost about $6 per thousand additional to put the timber in place.

"Vulcanized timber has been used on the New York Elevated Railroads for twelve years without showing any signs of material deterioration, and the chances are that it will last fully twenty-five years.

"Our investigations lead us to the conclusion that it costs about $1 per tie to replace ties in the track without interfering with the traffic, over and above the value of the tie itself; while for new work the cost of laying a tie is only 20 cents, making a difference of 80 cents.

"For the purpose of comparison let us take a mile of double track. The bill of timber therefor is as follows:

Ties....	9 052:	6 ins.	x 8 ins.	x	8 ft.....	289 664 ft.
Guards.	920:	6 "	x 8 "	x	24 ".....	88 320 "
Guards	920:	8 "	x 8 "	x	24 ".....	117 760 "
Planks..	5:	2 "	x 8 "	x	5 280 ".....	35 200 "
Joists ..	1 508:	4 "	x 8 "	x	8 ".....	32 171 "
						563 115 ft.
						Say 564 M.

"In order to be absolutely on the side of safety, let us assume the life of the vulcanized timber to be only fifteen years, or just twice that of the untreated timber, and that the excess of cost of replacing ties during traffic over that when there is no traffic is 60 cents instead of 80 cents per tie. The rate of compound interest assumed is 5 per cent. At the end of fifteen years, then, according to these assumptions, the floor in either case would have to be renewed, and the total costs for the fifteen years would be as follows:

For Vulcanized Timber.

564 M at $38.....	$21 432 00
Compound interest on $21 432 for 15 years..	23 125 13
Total.....	$44 557 13

For Untreated Timber.

564 M at $24	$13 536 00
564 M at $24	13 536 00
9 052 ties at 60 cents	5 431 20
Compound interest on $13 536 for 15 years	14 605 30
Compound interest on $18 967 for 7½ years	8 383 50
Total	$55 492 00

"According to these figures the untreated timber is about 25% more expensive than the vulcanized timber, even upon assumptions that are manifestly unfavorable to the latter."

XIII.—Best and Cheapest Material for Pedestal Caps.

Estimates of cost were made on several types of pedestal caps, including castings like those used on the Metropolitan Elevated, Kettle River sandstone blocks and granitoid; and the last was adopted because it was considered both the cheapest and best. Experience with the finished pedestals has given the company's engineers no reason to regret their decision concerning this matter. The granitoid covering for the concrete of the pedestals is 6 ins. thick, and is composed of one part of Portland cement, two parts of fine granite screenings and four parts crushed granite, no piece being too large to pass through a ring ¾ in. in diameter, the top surface being made extremely smooth, to exact elevation, and perfectly level.

XIV.—Bearing Capacity of Chicago Soil.

Mr. Rowe made a number of experiments on the bearing capacity of Chicago soil, using an apparatus designed by the author, by which a load of pig iron was applied centrally to a square block of timber. As Mr. Rowe has promised to treat this subject in his discussion, no further details will be given here, except to state that the safe load in some places ran as low as 1 ton per square foot.

XV.—Best Style of Anchorage for Columns.

Where longitudinal sway bracing is employed, two anchor bolts per pedestal were used; but, where reliance was placed on the transverse strength of the column to resist the bending effects of longitudinal and transverse thrusts, four anchor bolts per pedestal were employed. All the anchor bolts of each pedestal were passed through a single anchor casting or spider embedded in the concrete and set

very carefully to exact line and level. The details of the foundation are shown in Fig. 5. The upper ends of the anchor bolts are enclosed loosely with a curved steel plate, long enough to contain an ample number of rivets for attaching to the column, and having a square and smooth top to receive a heavy steel washer plate. As there are enough rivets connecting the curved plate to take care of both the direct and the secondary or induced stresses due to eccentricity, this entire pedestal detail is such as to make the column and the pedestal absolutely continuous, so that they act as a unit in resisting overturning; hence all calculations of strength of parts were made upon the assumption that the foot of the column is fixed.

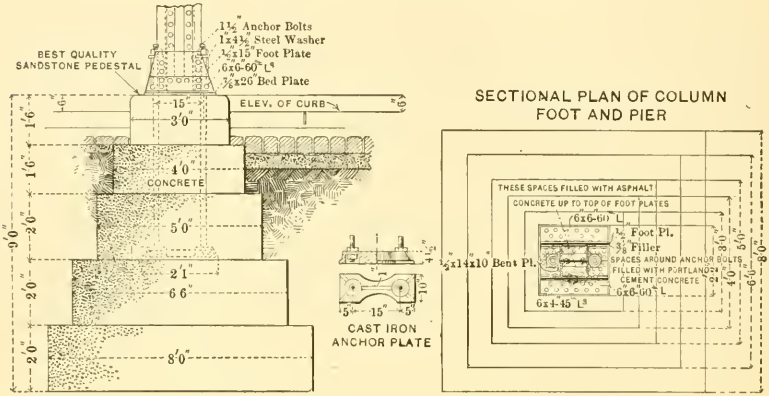


FIG. 5.

A detail similar to this was employed by the author in 1891 when designing the columns and pedestals of the Sioux City train-shed; and, as far as he knows, this was the first time that a column-foot detail involving a truly fixed end for the column was ever used.

The ordinary method of running the anchor bolts through the horizontal foot-plate of the column near its edges or corners does not make a fixed-end column—far from it, as a few simple calculations will show.

XVI.—PLATE GIRDERS *versus* OPEN-WEBBED GIRDERS.

In designing these elevated railroads for Chicago, many estimates for both plate and open-webbed girders have been made, which

demonstrate that there is practically no difference in the weight when both girders are properly designed. As the open-webbed girders cost a trifle more per pound to manufacture, there is no economy in their use; nevertheless they were adopted for all structures running longitudinally in the streets in order to comply with certain city ordinances.

The observance of these ordinances was sometimes carried to extremes, producing ridiculous combinations of solid and open web in the same girder, and an evident waste of material and labor. For this the engineers are not to blame, as it was not they who framed the ordinances.

XVII.—Crimping of Web-Stiffening Angles *versus* the Use of Filling Plates.

An investigation of this question was made by writing to a number of the leading bridge companies, and propounding to them this query: "If you had a lump sum contract for building a bridge would you find it more economical to use crimped angles for web stiffeners, or to adopt plain angles with fillers beneath them?" Some replies favored crimping and some did not; but the majority, including most of the larger companies, considered crimping a little the more economical, especially for intermediate stiffeners; consequently on the Chicago work all intermediate stiffeners are crimped, and all end stiffeners have filling plates.

XVIII.—Best Sections for Columns.

Investigation concerning strength, capacity to resist impact, facility of erection, economy of metal, etc., determined that the section for columns located in the street should be two 15-in. rolled channels with the flanges turned inward and a 15-in. rolled I-beam riveted between to act as a central web or diaphragm, the flanges of the channels being held in place by interior stay plates spaced about 3 ft. centers. In most cases the column feet pass below the pavement and are embedded in the concrete, to which, of course, they are bolted, but in some cases they rest on pedestals a little above the level of the sidewalk. The main object in turning the flanges inward is to enable the column better to resist impact from heavily loaded vehicles. Just

above the pavement there is a curved casting filled with concrete and surrounding the column to act as a fender.

This column is a very satisfactory one after it is erected, although it gives some little difficulty in the shops and involves a little more field riveting than usual. One complaint made was that the top and bottom planes of flanges of I-beams are never exactly parallel to each other, so that some straightening was necessitated.

For columns located on private property or on sidewalks where the structure is transverse to the street, four Z-bars and a web plate were adopted as the most satisfactory section. At the top of the column a wide curved web plate and curved angles are used. This design makes a most satisfactory column, which goes through the shops readily, and which is well adapted for quick erection. It is true that it necessitated a special tool for cutting the webs to a circle, but after this was made, the manufacture was easy and comparatively inexpensive. The Union Bridge Company, of Athens, Pa., and the Elmira Bridge Company, of Elmira, N. Y., together took the contract for the metalwork of the entire Northwestern Elevated and the Fifth Avenue side of the Union Loop. The Lake Street side of the Loop was built by the Phœnix Bridge Company of Phœnixville, Pa., and the other two sides are being built by the Pencoyd Iron Works of Pencoyd, Pa.

Figs. 6 and 7 illustrate features of the column construction, the latter figure also showing the details of an expansion joint.

XIX.—Best Style of Expansion Joint.

The designing of a perfectly satisfactory expansion joint is no simple problem ; consequently, it demanded considerable study, the result of which was the adoption of the pocket shown in Figs. 8 and 9 to receive the loose end of a longitudinal girder. The most important feature of this design is that the center of pressure from the longitudinal girder is distant from the cross-girder about half the length of the pocket, which reduces the moment due to eccentricity upon the group of rivets connecting the pocket to the cross-girder, and prevents the bearing of the longitudinal girder from coming on an edge of metal as would be the case were not the center of pressure thrown towards the cross-girder by the small base plate. Again, the number of rivets connecting the pocket to the cross-girder is ample for both the direct

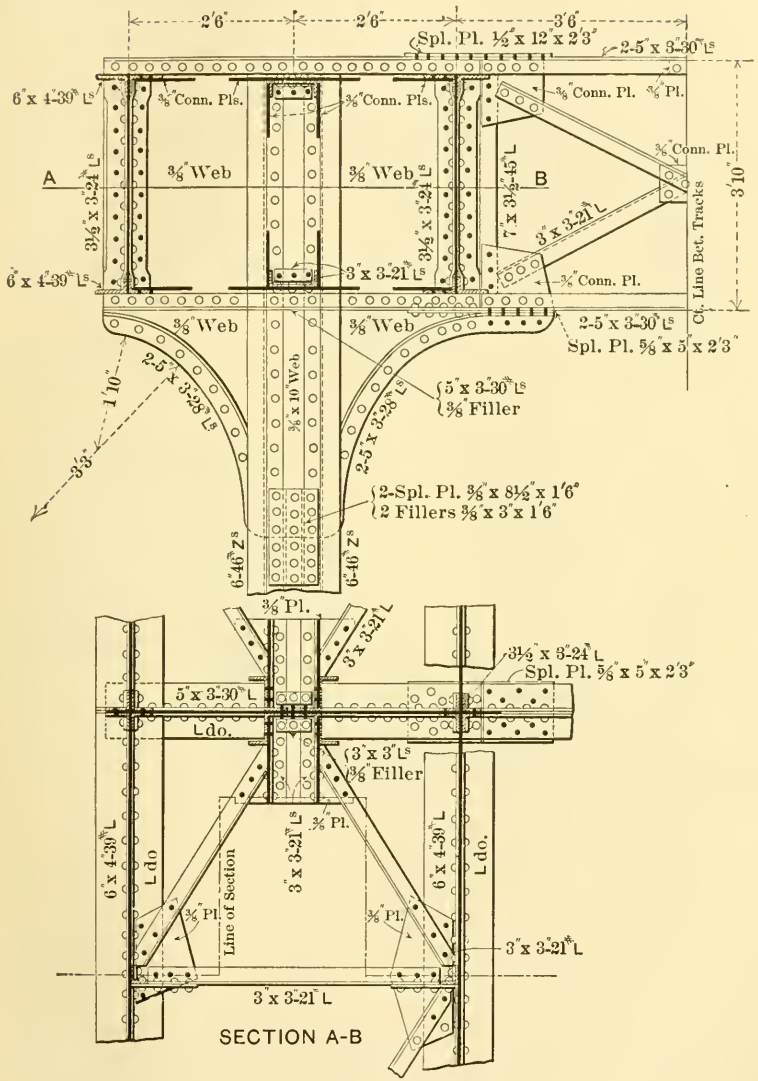

2'6"
2'6"
3'6"
Spl. Pl. ½" x 12" x 2'3"
2-5" x 3-30" Ls
6" x 4-39" Ls
⅜" Conn. Pls.
⅜" Conn. Pls.
⅜" Conn. Pl.
⅝" Pl.
⅜" Conn. Pl.
A
⅜" Web
⅜" Web
B
3½" x 3-24" Ls
3½" x 3-24" Ls
7" x 3½-45" L
3" x 3-21" L
3'10"
6" x 4-39" Ls
3" x 3-21" Ls
⅜" Conn. Pl.
Ct. Line Bet. Tracks
⅜" Web
⅜" Web
2-5" x 3-30" Ls
Spl. Pl. ⅝" x 5" x 2'3"
2-5" x 3-28" Ls
1'10"
⅜" x 10" Web
2-5" x 3-28" Ls
5" x 3-30" Ls
⅜" Filler
3'3"
2-Spl. Pl. ⅜" x 8½" x 1'6"
2 Fillers ⅜" x 3" x 1'6"
6-46" Zs
6-46" Zs
⅜" Pl.
3" x 3-21" L
3½" x 3-24" L
Spl. Pl. ⅝" x 5" x 2'3"
5" x 3-30" L
Ldo.
3" x 3" Ls
⅜" Filler
⅜" Pl.
6" x 4-39" L
Ldo
3" x 3-21" Ls
Line of Section
6" x 4-39" L
Ldo.
⅜" Pl.
⅜" Pl.
3" x 3-21" L
3" x 3-21" L
SECTION A-B

FIG. 6.

shear and the secondary stresses due to the moment caused by the eccentric bearing. The longitudinal girder fits tightly laterally in the pocket, and its top is held between angle clips riveted to the cross-girder. Thus the expansion ends of the longitudinal girders are held

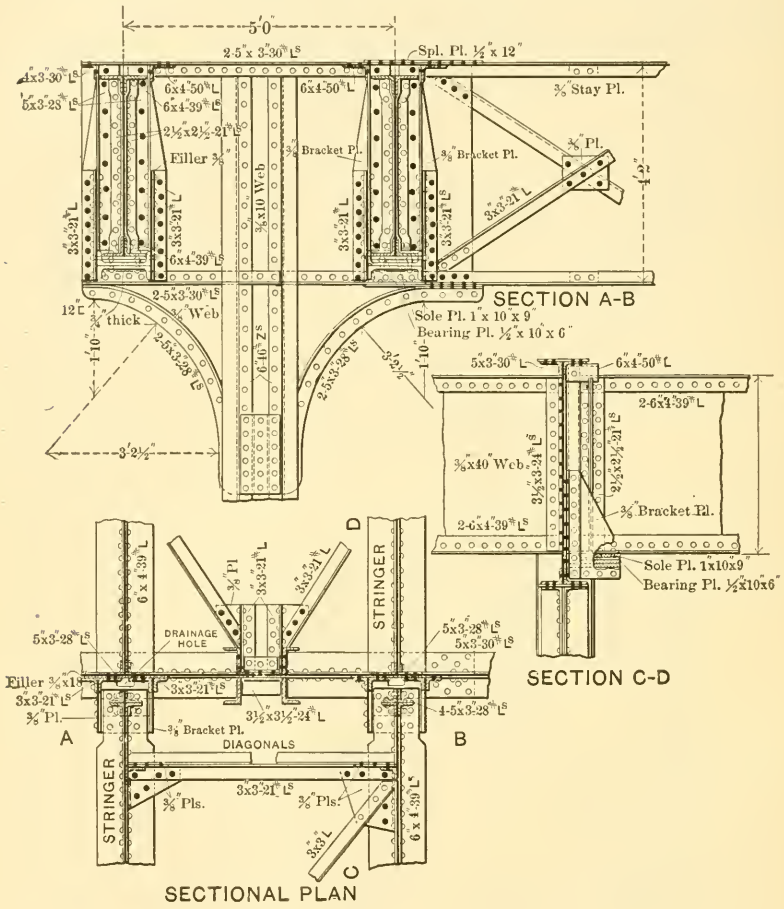


FIG. 7.

laterally to the cross-girders just about as rigidly as are the riveted fixed ends.

The detailing of the entire expansion end is so arranged that all parts of the metalwork are accessible to the brush for painting, al-

though extra care will have to be used by the painter on this portion of the structure, in order to make sure that no portion of the surface is unprotected.

XX.—Style of Bracing on Curves.

The extra bracing on curves is composed of two lower lateral systems, each pertaining to two tracks, and consisting of a double system of cancellation, the diagonals being formed of two 4 x 3-in. angles riveted together and to the lower flanges of the longitudinal girders where they cross the same. The columns on curves are made larger and stronger than those on tangents, in order to resist properly the centrifugal loads.

XXI.—Proper Limit of Length of Structure between Expansion Joints.

This question involves the effects of changes of temperature, more especially in producing bending on the columns. The latter were figured for deflection with due regard to the fixedness of their ends, which increases the extreme fiber stresses due to changes of temperature. The investigation showed that 150 ft. should be the ordinary limiting distance between expansion points. On almost the entire lines of the Northwestern and Loop, this limit was observed; but in two or three cases, owing to peculiar local conditions, it had to be exceeded. In these cases, however, the columns most affected were strengthened.

XXII.—Track-Bolt Nuts Above *versus* Track-Bolt Nuts Below.

Each method has both good and bad features. With nuts below, the hole through the wood can readily be protected from the entrance of water, but the nuts may work off the bolts without notice being taken of the fact by the track-walker. With nuts above, any loosening of the bolts would be seen at once, but a water-tight joint is hard to make. The latter arrangement, after much discussion, was adopted, and cup-shaped washers let into the wood were employed. A liberal use of paint in these cups will probably seal them against percolation of water, but their insertion in the wood seems like an invitation for rot. An important advantage in using these cups is that there are no projecting nuts above the wood to trip anyone walking over the track.

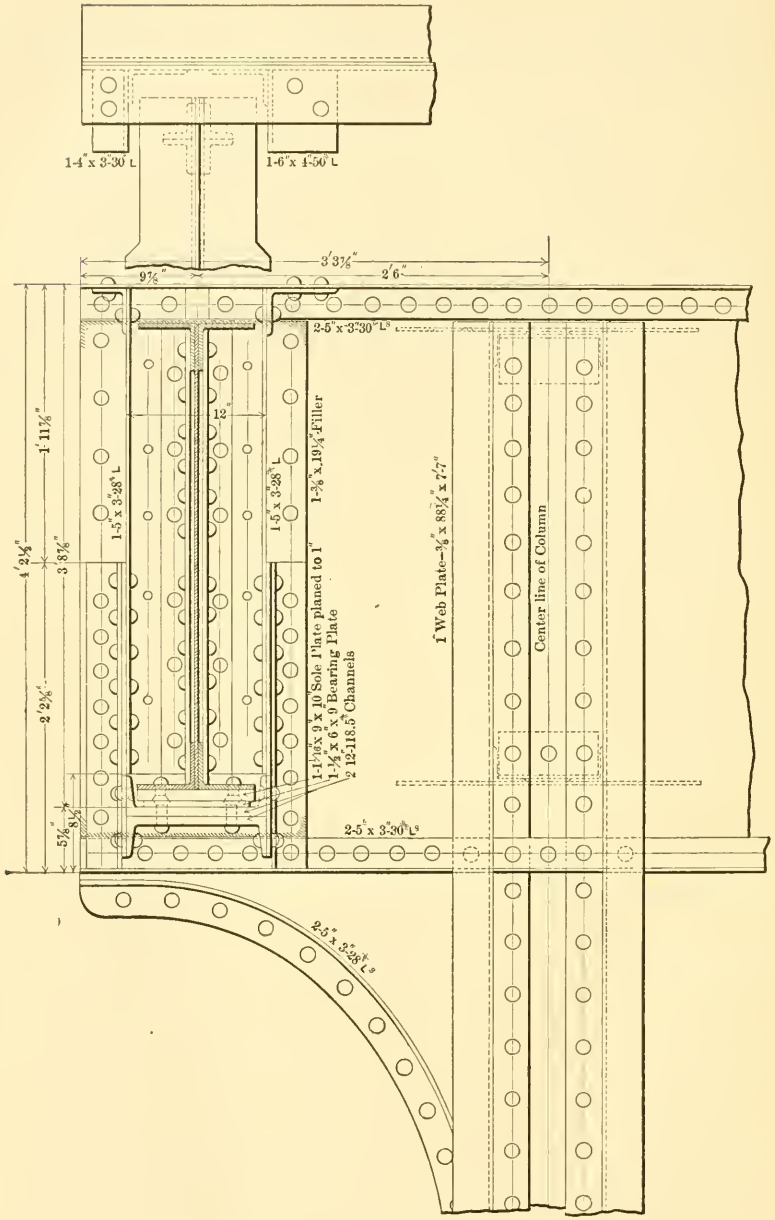

1-4" x 3"-30 L
1-6" x 4"-50 L
3' 3⅞"
9⅞"
2' 6"
2-5" x 3"-30" Ls
12"
1-5" x 3"-28" L
1-5" x 3"-28" L
1-⅜" x 19¼" Filler
1-1 5/16" x 9" x 10" Sole Plate planed to 1"
1-½" x 6" x 9" Bearing Plate
2 12"-118.5# Channels
1 Web Plate—⅜" x 88¼" x 7'-7"
Center line of Column
2-5" x 3"-30" Ls
2-5" x 3"-28" Ls
1' 11⅞"
4' 2½"
3' 8⅞"
2' 2⅝"
5⅞"
8½"

FIG. 8.

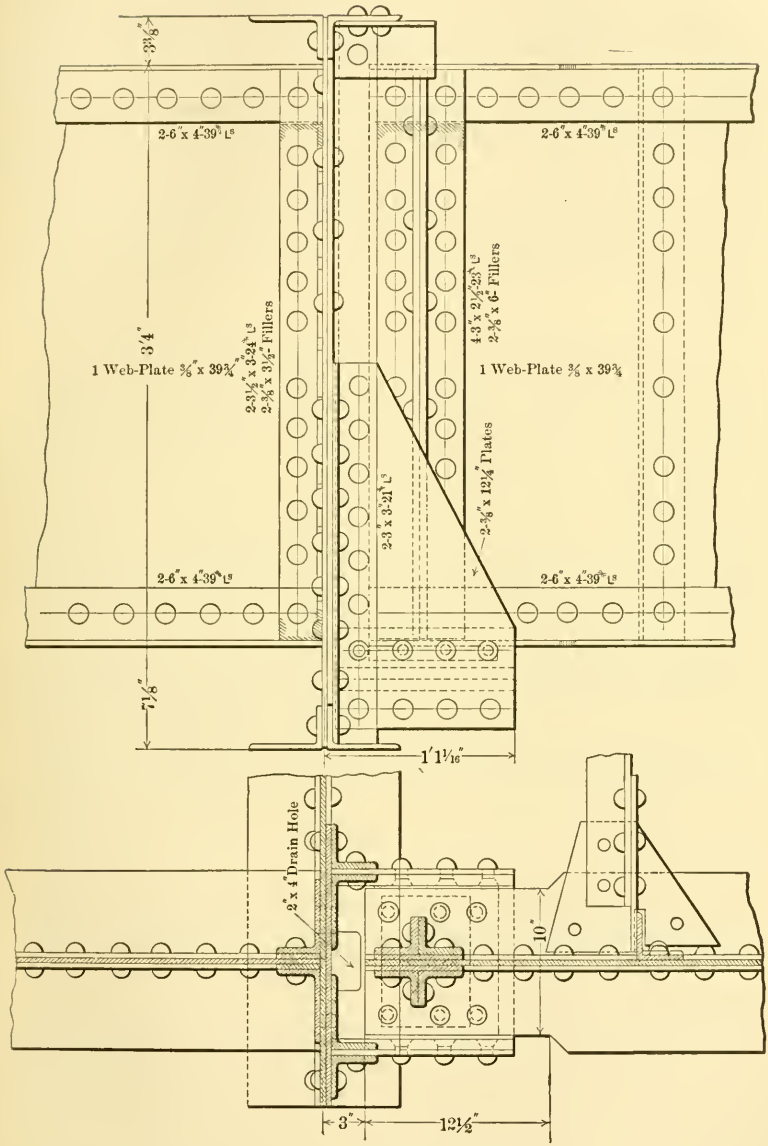

3⅜"
2-6" x 4"-39# Ls
2-6" x 4"-39# Ls
3'4"
1 Web-Plate ⅜" x 39¾"
2-3½" x 3"-24# Ls
2-⅜" x 3½" Fillers
4-3" x 2½"-23# Ls
2-⅜" x 6" Fillers
1 Web-Plate ⅜ x 39¾
2-3" x 3"-21# Ls
2-⅜" x 12¼" Plates
2-6" x 4"-39# Ls
2-6" x 4"-39# Ls
7⅛"
1'1 1/16"
2" x 4" Drain Hole
10"
3"
12½"

FIG. 9.

XXIII.—Superelevation on Curves.

It was decided not to attempt to obtain this by elevating or depressing the longitudinal girders, or by using wooden shims on outer girders, but to employ wedge-shaped ties. Three bevels only are used on the line, viz., 1, 2 and 3 ins. in 5 ft. Such bevels, it is true, will not afford the theoretical superelevation required for the maximum speed on sharp curves; but it was considered that this maximum speed could not be maintained on sharp curves, hence the compromise between theory and practice. Experience in operation alone will tell whether the decision of the company's engineers in this matter is correct.

XXIV.—Best Styles of Stations.

For stations on the company's private property it was decided to adopt a single brick house to accommodate the entering passengers for all four tracks, the exit passengers leaving the platforms by special exit stairways leading to or near the street, each of said stairways being provided at its foot with a turnstile prohibiting entrance but permitting exit. This arrangement dispenses with several platform employees and prevents the station house and stairways from obstruction by passengers moving in opposite directions.

At first it was intended to run the exit stairways at right angles to the line and land on the sidewalks of the cross-streets, as shown in Fig. 10, but it was found afterwards that this method would in some cases involve the payment of unduly high damages to property-owners, so it was decided to confine these stairways entirely to the company's property, as in Fig. 11. From the operating point of view the first design is the better one in that it does not cut up the already somewhat narrow platforms with apertures for exit, as does the design adopted. However, the pressure of the financial department was too strong for the engineers; consequently, the proposed change was adopted.

The following extracts from the specifications for stations on the Northwestern Elevated, together with occasional reference to Figs. 10 and 11, will give a fairly clear idea of what these stations will be like when completed.

"There are two slightly different styles of stations on the line, viz.: 'Interior Track Stations' and 'Exterior Track Stations,' the

former being placed at intervals of about one mile, and the latter at intervals of about a quarter of a mile.

"The essential points of difference in the two styles of stations are in the platforms and in the vestibule and stairways leading thereto.

"In the Exterior Track Stations the platforms are outside of the tracks, while in the Interior Track Stations they are between the exterior tracks and those adjacent thereto, the exterior tracks being spread so as to pass around the platforms.

"There will be but one house to each station, passengers entering the same from the street, but not passing through it when leaving the line, as special exit stairways leading to the street are provided.

"The houses are to be built as follows: The basement walls are to be composed of rubble, resting on dimension stone footings; the main walls are to be of common brick, faced with pressed brick and terra cotta trimmings; the roof is to be a composition gravel roof; the floors are to be of white oak, resting on common yellow pine flooring over yellow pine joists; and the finish is to be of antique oak. The houses are to be lighted by both electricity and gas, and are to be heated by hot water.

"The ticket office is located to one side of the rear vestibule, which latter leads to the entrance stairways, which in turn lead to the platforms.

"These platforms are to be constructed of transverse and longitudinal timbers with a two-inch (2") vertical-grain yellow pine flooring on top. They are to be sheltered by canopies of corrugated iron supported by steel frame construction.

"Around all stairway openings, along the outside of exterior platforms, and at ends of all platforms are to be gas-pipe hand-railings paneled with grillework screens."

XXV.—Best Method of Heating Stations.

After considerable deliberation and discussion it was decided to heat all stations with hot water. This is undoubtedly the most satisfactory method for houses on the ground; but for the Loop stations and those of the Northwestern which are supported by the metalwork, the author would have preferred heating by gas so as to avoid the carrying to and fro of coal and ashes, with the unavoidable accompanying dirt and trouble. The use of gas, though, would have been more expensive than that of coal.

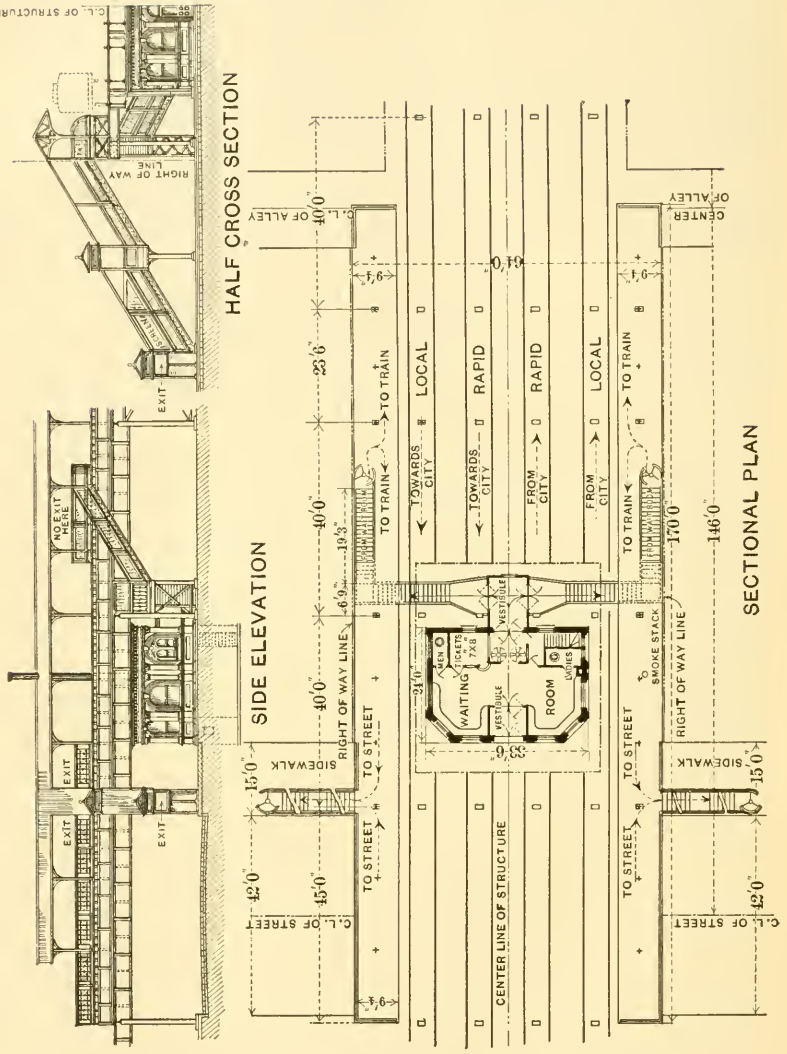
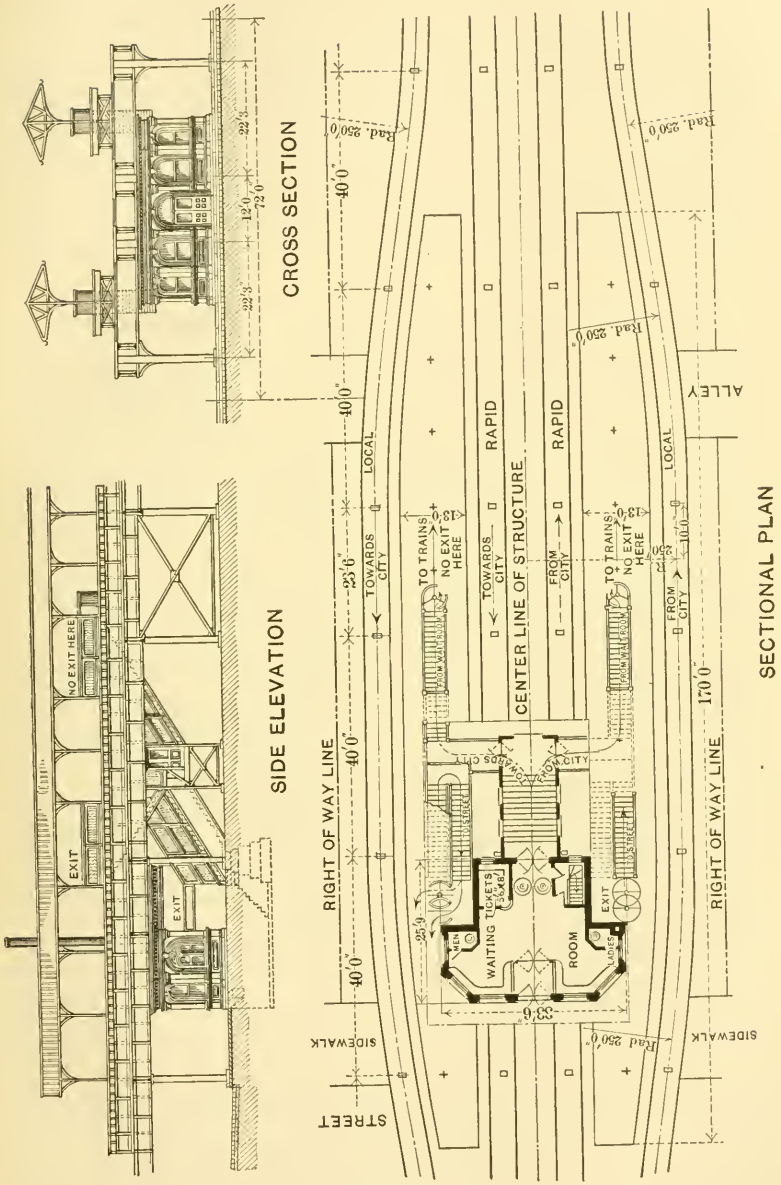

HALF CROSS SECTION
SIDE ELEVATION
SECTIONAL PLAN
C.L. OF STRUCTURE
RIGHT OF WAY LINE
EXIT
NO EXIT HERE
C.L. OF ALLEY
CENTER OF ALLEY
TO TRAIN
TOWARDS CITY
FROM CITY
LOCAL
RAPID
RIGHT OF WAY LINE
SIDEWALK
TO STREET
C.L. OF STREET
CENTER LINE OF STRUCTURE
SMOKE STACK
WAITING ROOM
MEN
TICKETS 7X8
VESTIBULE
LADIES
40'0"
23'6"
19'3"
6'9"
15'0"
42'0"
45'0"
64'0"
170'0"
146'0"
33'6"
24'0"

FIG. 10.


CROSS SECTION
SIDE ELEVATION
SECTIONAL PLAN
NO EXIT HERE
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RIGHT OF WAY LINE
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CENTER LINE OF STRUCTURE
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LOCAL
LOCAL
TOWARDS CITY
FROM CITY
TO TRAINS NO EXIT HERE
FROM WAIT ROOM
WAITING TICKETS
ROOM
MEN
LADIES
EXIT
STREET
SIDEWALK
ALLEY
Rad. 250'0"
40'0"
23'6"
170'0"
33'6"
25'9"
13'0"
10'0"
72'0"
12'0"
22'3"

FIG. 11.

XXVI.—Relative Costs of Double-Track Structure with Columns in the Street and with Columns Just Inside of Curb Lines.

This question was investigated so as to determine whether in certain cases it would be worth while to strive for permission to put the columns in the street. As will be seen in the table given under Section XXVIII, the cost of structure per mile of double track was estimated to be $267 760 with columns inside of curbs, and $240 537 for columns in street, making a difference of $27 223 per mile of double track, or a relative difference of between 11 and 12 per cent.

XXVII.—Pressed-Thread Bolts *versus* Cut-Thread Bolts.

As the manufacture of pressed-thread bolts is a patented process, the author first obtained from the patentees a guaranteed pound price for their bolts delivered f. o. b. cars Chicago, at the same time getting corresponding prices for both upset and plain bolts with cut threads. He then had his metal inspectors test to destruction several specimens of pressed-thread bolts so as to determine their strength in comparison with cut-thread bolts.

As the difference in the pound prices was small, and as the strength of the pressed-thread bolts is fully 50% greater than that of the cut-thread bolts, the comparison resulted greatly in favor of the former, so they were adopted for all the anchor bolts and track bolts on both lines of road. The author feels that he cannot speak too highly of these pressed-thread bolts, for the results of the tests were surprising. When it is considered that the cold-pressing process reduces the effective diameter of the soft steel rod at the root of the thread, and in fact increases it but little at the edges, it might be imagined that when the bolt is tested to destruction, it would break in the threaded portion. Such, however, is not the case, for all the specimens broke in the body of the rod, and, strange to say, the threads were so little injured that the nuts could be turned readily over the whole length of same.

XXVIII.—Studies Involving a Number of Designs for Different Styles of Structure.

The investigations included under this heading are the most elaborate of all those made. They involved careful designs and estimates

of cost of the following types of structure, all of which are shown in cross-section in Figs. 12 to 24 inclusive.

Design 1. Four-track structure with longitudinal bracing, supported by four Z-bar columns, the cantilevers and columns being made in one piece in the shops.

Design 2. Similar to Design 1, except that the cross-girders are riveted to the columns in the field, and the brackets are omitted.

Design 3. Four-track, two-column structure, with longitudinal bracing.

Design 4. Four-track, four-column structure, without longitudinal bracing.

Design 5. Four-track, two-column structure, without longitudinal bracing.

Design 6. Double-track, two-column structure, with longitudinal bracing, similar to Design 1.

Design 7. Double-track, two-column structure, with longitudinal bracing, similar to Design 2.

Design 8. Double-track, two-column structure, with longitudinal bracing, the columns being spaced 17 ft. centers transversely to the structure.

Design 9. Double-track, two-column structure, without longitudinal bracing, similar in construction to Design 4.

Design 10. Four-track, four-column structure, without longitudinal bracing, the columns being flared out at the top and extending only to the plane of the bottoms of stringers, and the column section being composed of two 15-in. I-beams.

Design 11. Four-track, four-column structure, similar to Design 10, except that channels are used instead of I-beams in the columns.

Design 12. Double-track, two-column structure, without longitudinal bracing, for the alternative route along Fifth Avenue and Franklin Street, the columns being placed on the curbs.

Design 13. Double-track, two-column structure, without longitudinal bracing, also for the alternative route along the streets, the columns in this case being placed in the roadway.

The following is an almost verbatim extract from the author's report, all references to drawings being omitted.

In explaining and discussing each of these designs, the following questions in the order here given will be considered: First, general description; second, strength; third, rigidity; fourth, economy; fifth, æsthetics; sixth, uniformity of construction; seventh, facility of manufacture and erection.

In making these various calculations there has been assumed a typical block 292 ft. long, simply for purposes of comparison. This block, however, is of about the average length of the blocks through which the line will pass.

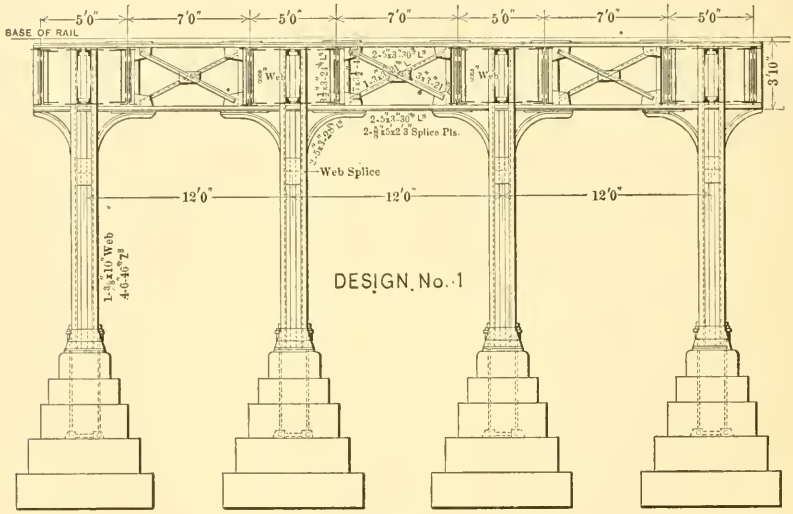


Fig. 12.

Design 1, Fig. 12.

Design 1 is a four-track structure which is supported by four Z-bar columns.

General Description.—Each track is carried by a column which is located directly beneath its central line. The stringers are spaced 5 ft. apart, and are, therefore, almost directly beneath the rails. They are carried by short cantilevers, one on each side of the column. The web of these two cantilevers and that of the top of the Z-bar column are all in one piece, this web being carried through the top of the column. The top flange of the cantilevers is also continuous over the top of the column, and its web is carried far enough down the column to form a good bracket on each side.

The spans are all to be 40 ft. in length, excepting those over the street, which are 45 ft., and those having longitudinal bracing, which are 23 ft. 6 ins. There will be two such braced spans to each 292-ft. block, and a correspondingly greater number for blocks of greater length. This longitudinal bracing is designed to take up the entire horizontal thrust due to braked trains or to traction, the intermediate columns being designed to carry only the direct load and transverse thrust from wind load.

The stringers or longitudinal girders are plate girders, riveted up solidly to the cantilever brackets, except at the expansion ends. The expansion joints are spaced about 150 ft. apart, and will be similar in design to those used on the Wabash Avenue Extension of the Lake Street Elevated Railroad. The longitudinal thrust due to expansion and contraction of the stringers is carried to the column in each bent by short struts, but the longitudinal thrust due to braked trains is carried by the stringers directly to the longitudinal bracing.

On curves, where permissible, a system of vertical sway bracing will be used, and, where it cannot be employed, the columns will be made strong enough to transmit the transverse thrust to the pedestals.

These pedestals are to be made of concrete, covered with granitoid.

Strength.—Every portion of this structure has been made amply strong to carry the greatest stresses and loads which can come upon it. It would be difficult to make stronger or more efficient columns and cantilevers than the ones used throughout this design; for these columns, cantilevers and brackets are made in one piece in the shops, and there is not a weak point in them.

The bracing towers, if they may be so termed, are well braced, both longitudinally and transversely in vertical planes, and horizontally at the top, and take care most effectively of the total longitudinal thrust.

Rigidity.—The stringers are thoroughly braced together so as to prevent as much as possible all transverse vibration, and this bracing, together with the longitudinal sway bracing in the towers, prevents any undue longitudinal vibration. As the columns are placed directly beneath the centers of the tracks, there is no possibility of unequal deflection in the transverse girders and cantilevers, such as might occur if the columns were not so placed. All columns are anchored to the pedestals by long anchor bolts which extend well into the concrete and make the column and pedestal act as one piece. Upon the whole this design is so constructed as to make it as rigid a structure as can be obtained.

Economy.—While this structure has been made thoroughly first class in every respect, no material has been wasted in so doing. The spans have been made of the most economical lengths; the spacing of columns transversely to the structure, the sections of columns used, the style of cantilever and the stringer bracing are all examples of true

economy of design, but probably the feature that saves more metal than any other is the use of longitudinal sway bracing in the towers, as will be seen by comparing the weights of Designs 4, 10 and 11, and the one now under consideration. This comparison shows that from 140 lbs. to 165 lbs. of metal per lineal foot of structure have been saved in Design 1, or from $8 000 to $11 000 per mile of same, and at the same time a more rigid and stronger structure has been evolved than that illustrated in any of the other four-track designs.

From an economic point of view, only one of the designs, viz., Design 3, offers any advantage over Design 1, but there are other considerations which offset this apparent economy in Design 3.

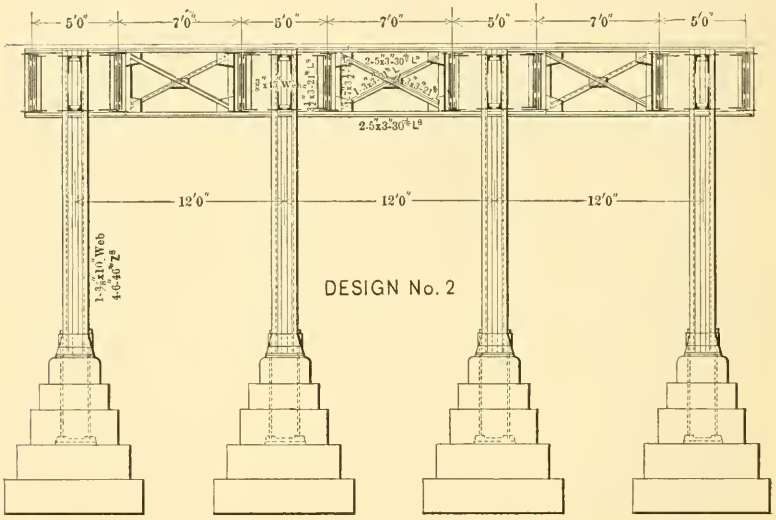


FIG. 13.

Æsthetics.—This structure is light and airy, and upon the whole presents a very neat appearance; more so, perhaps, than any one of the other designs.

Uniformity of Construction.—The style of construction will be the same throughout, with only very slight alterations at stations and on curves, the double-track structure included. This will not be true of several of the other designs.

Facility of Manufacture and Erection.—The style of column used makes it practicable to do nearly all of the riveting in the shops, the cantilevers and brackets, as before stated, forming a part of the column. As the cross-girders have no direct load to carry whatsoever, they are made very light, and are to be connected to the cantilevers in the field, the rivets necessary to make this connection, to-

gether with those connecting the stringers to cantilevers and sway bracing, being the only field rivets required.

The work is all plain and straight, excepting the curved brackets. All parts are made of as few pieces as possible, and there are no large or unwieldly members to handle.

This design will be easier to manufacture and erect than any one of the other designs now under consideration.

Design 2, Fig. 13.

This is similar to Design 1.

Strength.—As far as the strength of the various parts of the structure is concerned, this design is almost the same as Design 1. The same sections are used in the stringers, columns, cross-girders and transverse and longitudinal bracing.

Rigidity.—This design will not be quite so rigid as Design 1, as there are no brackets beneath the cross-girders, and the method of connecting the cantilevers and cross-girders to the columns is not so good, for in Design 1 the cantilevers and columns are all made in one piece; otherwise, the two designs are identical.

Economy.—The cost of Design 2 is the same as that of Design 1, viz., $65 10 per lineal foot (average), including curves.

Æsthetics.—Owing to the omission of the brackets, this design does not appear so well as does Design 1.

Uniformity of Construction.—What was said of Design 1 applies to Design 2 as well.

Facility of Manufacture and Erection.—In this case the cantilevers and cross-girders are riveted up to the columns in the field; this necessitates driving more rivets in the field than in case of Design 1, but all the work is plain and straight, and will be easy to manufacture and erect. Taking it as a whole, this design is not quite so satisfactory as Design 1, and it costs quite as much money.

Design 3, Fig. 14.

Strength.—Design 3, as well as all the others, has been made good and strong in all its details.

Rigidity.—This design is a two-column, four-track structure, with the two outer tracks cantilevered out beyond the columns, which are spaced 24 ft. centers in planes transverse to the structure. While the structure has been designed to be as rigid as is possible with this style of construction, the unequal distribution of load and the lengths of cantilever and girder necessary do not insure the rigidity which is obtained in Designs 1 and 2.

Laterally, the structure is well braced; and, longitudinally, the braced towers are used, as in the preceding designs.

Economy.—This design is a trifle cheaper than Designs 1 and 2, on account of the saving in pedestals, the metalwork costing considerably more, though, than in those designs.

Cost of Design 1.....	$65 10
Cost of Design 3.....	64 60
Difference.....	$0 50, or $2 640 per mile.

Æsthetics.—This structure is by no means a good-looking one.

Uniformity of Construction.—In this design in changing from four-track to double-track structure, it will be necessary to change en-

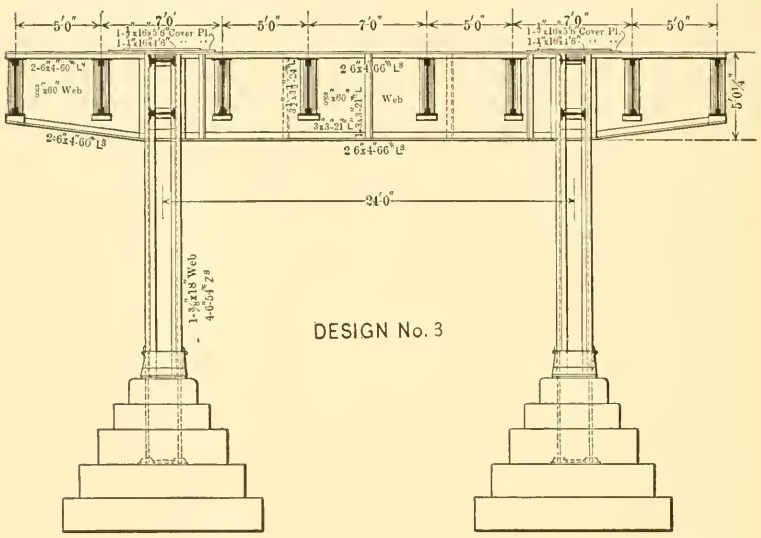


FIG. 14.

tirely the style of construction, which is not the case in Designs 1 and 2.

Facility of Manufacture and Erection.—In this design all cross-girders and cantilevers must be riveted to the columns in the field, and, owing to the great depth of these girders, this will make this structure difficult to erect. The girders are all heavy and unwieldy, much more so than in the four-column structures. The work in the shops will be easy.

While the structure is, perhaps, apparently a little more economical than Design 1, it has the disadvantages of being unsightly, of lacking rigidity, and of being difficult to erect.

Design 4, Fig. 15.

General Description.—Design 4 differs from Designs 1, 2 and 3 in the fact that no longitudinal sway bracing is used, but each column is made strong enough to take up the longitudinal thrust coming upon it. The spans through the blocks are about 50 ft. long.

This is a four-column, four-track structure, each column being fixed at top and bottom in planes transverse and parallel to the structure. The columns are anchored to the pedestals by four anchor bolts instead of two, as in the preceding designs.

Rigidity.—As the only longitudinal rigidity obtained is solely through the efficiency of the columns to resist bending, it is evident that

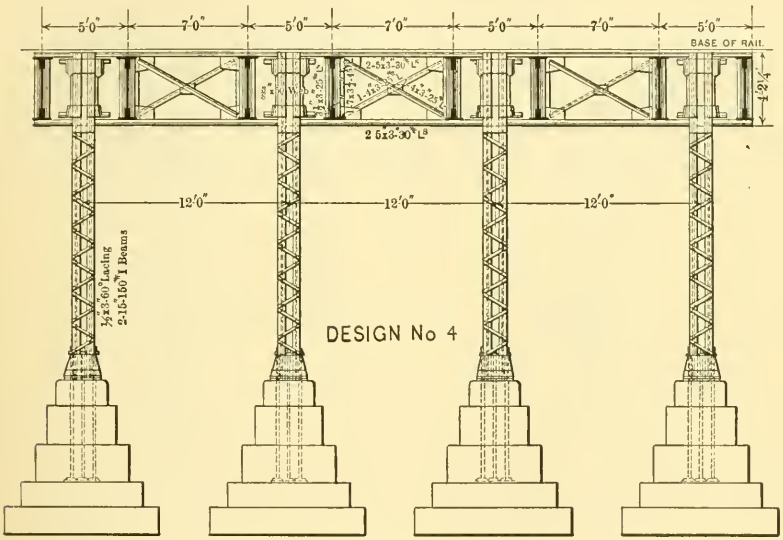


Fig. 15.

this design will not be as rigid in this direction as Designs 1, 2 and 3. There are no brackets transverse to the structure; hence, it will not be as rigid laterally as Design 1. The stringers are well braced together and to the columns. On curves, transverse sway bracing will be used where permissible, and where it is not, the columns will be strengthened, so as to take care of the centrifugal load.

Economy.—This is the most expensive design yet considered, the average cost per lineal foot being $66 65 instead of $65 10 for Design 1.

Æsthetics.—Design 4 has nothing to commend it from an æsthetic point of view.

Uniformity of Construction—Like Designs 1 and 2, this design has the advantage of being adapted to both double and four-track structures.

Facility of Manufacture and Erection.—This design would be easier to erect than Design 3, but not so easy as Design 1. The shopwork would be somewhat difficult.

Design 5, Fig. 16.

General Description.—This is a two-column, four-track structure, and, like Design 4, has no longitudinal sway bracing. The columns are built up of plates and angles, and are designed to carry the longitudinal and transverse thrusts due to braked trains and to wind load. The spans are of the same lengths as in Design 4.

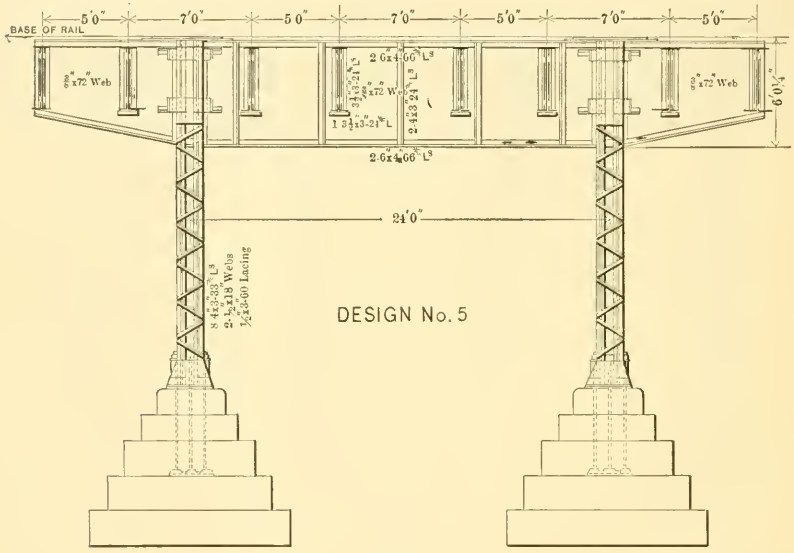


FIG. 16.

Rigidity.—The remarks made under this head for Design 3 apply to Design 5 as well; but, in addition to the defects of the former, Design 5 lacks the longitudinal sway bracing, and so will not be as rigid as Design 3.

Economy.—Design 5 is the most expensive design on the list, the cost per lineal foot being $67 60.

Æsthetics.—Like Design 4 it has no commendable features in this respect.

Uniformity of Construction.—Like Design 3 this style of structure could only be made to apply to the four-track railway.

Facility of Manufacture and Erection.—The style of columns used would be somewhat difficult to manufacture, and the great amount of field riveting would make the erection expensive.

From the foregoing facts it will be seen that this design has several disadvantages and is also very expensive, although it has some good features.

Design 6, Fig. 17.

General Description.—Design 6 is similar to Design 1, but is a double-track structure. The remarks under Design 1 in relation to rigidity, æsthetics, and facility of manufacture and erection apply to this case also.

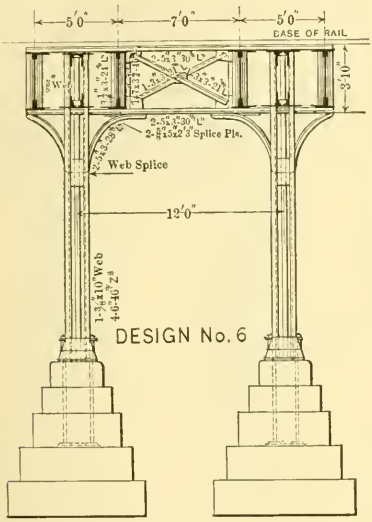


Fig. 17.

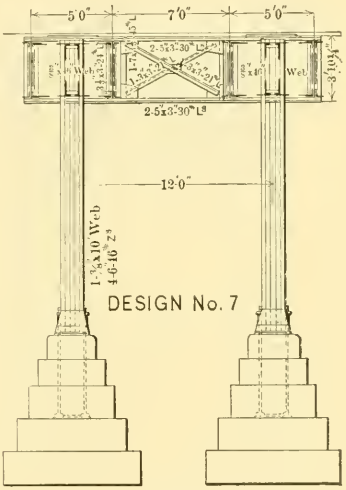


Fig. 18.

Economy.—The cost per lineal foot is $32 65.

Uniformity of Construction.—By using this design for double-track structure and Design 1 for the four-track structure, the design will be the same for columns, stringers, bracing towers, expansion ends, etc., throughout the whole line. If at any time it be considered necessary to convert double-track structure into a four-track structure, it can be done by simply adding a column at each side of the double-track structure, and putting in the additional stringers, cross-girders, and sway bracing.

Design 7, Fig. 18.

Design 7 bears the same relation to Design 2 that Design 6 bears to Design 1. The cost per lineal foot will be $32 65.

Design 8, Fig. 19.

General Description—In this design, which is for double track, the columns are made of four Z-bars, as in Designs 1, 2, 3 and 6, but instead of the columns being directly beneath the center of the tracks, they are placed beneath the outer stringers, thus making the spacing 17 ft. centers, transverse to the structure.

Strength.—The end webs in the cross-girders extend through the columns, forming the webs of the latter at the top, and pass down far enough to form good brackets, thus making the column, end of cross-girder, and brackets all in one piece, which is riveted up solidly in the shop. This makes a very strong connection.

Longitudinal bracing towers are used as in Designs 1, 2, 3, 6 and 7.

Rigidity.—This design is thoroughly braced in all directions, and will be very rigid; but as the columns are attached to the outer stringers, and as the inner stringers are supported by the cross-girders, it is probable that there will be some unequal deflection in the stringers; otherwise this design will be as rigid as Design 6.

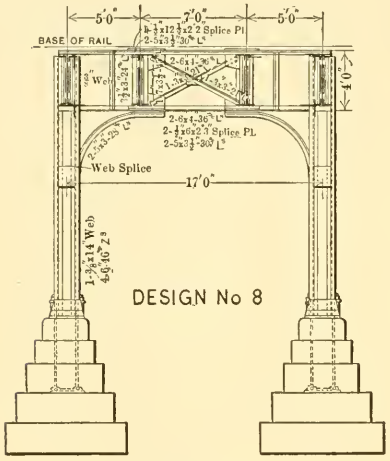


Fig. 19.

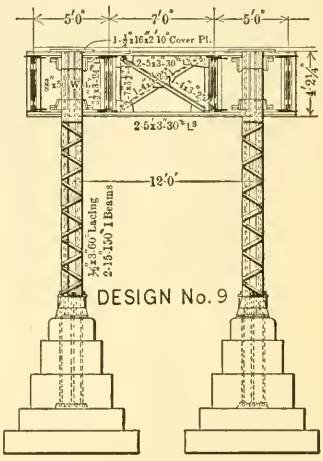


Fig. 20.

Economy.—This is the cheapest design on the list for a double-track structure, the average cost per lineal foot being $32 30, while Designs 6 and 7 each cost $32 65. This shows a saving of 35 cents per lineal foot, or $1 850 (nearly) per mile of double track.

Æsthetics.—The cross-section of this design is probably the most æsthetic of any of the designs, and the side elevation at street crossings can be improved by putting in longitudinal brackets beneath the outer stringers.

Uniformity of Construction.—This design necessitates considerable change in the style of construction from that used in the four-track

structure, and it would be difficult ever to convert the double-track structure into a four-track structure in case it should be considered advisable to do so at some future time.

Facility of Manufacture and Erection.—The style of columns and cross-girders used dispenses with nearly all of the field riveting, and will make this a very easy structure to erect. In the shop the work will also be very easy. The lateral system on curves and the stringer bracing used throughout the structure will be easier to connect to the columns and stringers in this design than in any of the other double-track structures now under consideration.

With the exception of the lack of uniformity in construction this design probably offers more advantages than any other for the double-track structure.

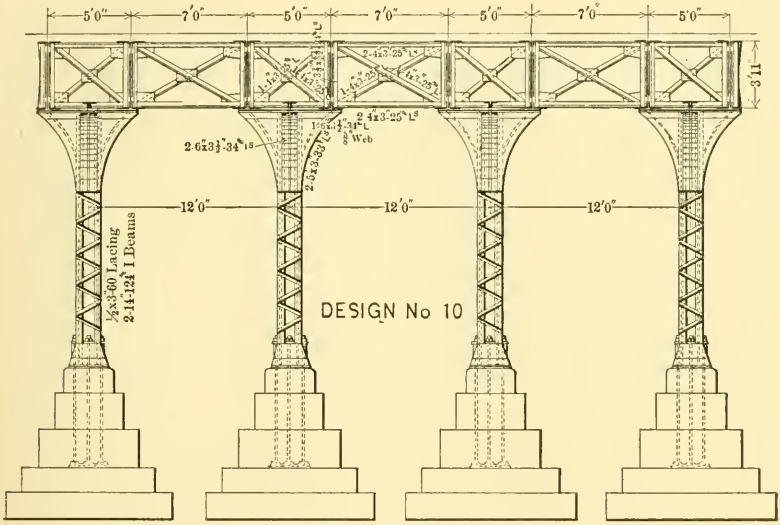


FIG. 21.

Design 9, Fig. 20.

Design 9 is a double-track structure similar in construction to Design 4, and the remarks made under the latter in relation to strength, rigidity, economy, æsthetics, uniformity of construction and facility of manufacture and erection apply to this case also. The cost per lineal foot is $33 31.

Design 10, Fig. 21.

Design 10 is different from any of the designs yet considered, for in all these the columns are carried up to the tops of the cross-girders, while in this the column is carried up only to the plane of the bottom of the stringers, the top of the column being flared out wide enough to receive the two track stringers, which are spaced 5 ft. centers. No

longitudinal bracing is used, so each column is figured to take up in bending its share of the longitudinal thrust.

The columns are made of two I-beams, well laced from the bottom up to the point where the flaring begins, and from this point to the top a large plate is riveted on each of the transverse faces of the column. This design is somewhat similar to the design used on the Metropolitan Elevated Railway of Chicago.

Strength.—Design 10 has been made amply strong in all of its parts.

Rigidity.—As the columns are placed directly beneath the center line of the tracks as in Designs 1, 2, 4, 6, 7 and 9, there will be but little vibration or deflection so far as the vertical loads are concerned, but, as the columns are not carried up to the tops of the stringers and cross-girders, it is impracticable to make the structure rigid against the longitudinal thrust due to braked trains. Longitudinal brackets have been used to fix the upper ends of the columns; but as each of these brackets has to take hold at the center of a small I-beam 5 ft. long, it is evident that the only rigidity that can be procured in this way is dependent upon the efficiency of this I-beam to resist bending, and a very small deflection in the I-beam will permit of considerable deflection in the column. With this bracket and connection, it is not legitimate to call the column fixed at the top. The stringers are well braced together, and the structure would be very rigid laterally, both on tangents and on curves.

Economy.—This design will cost $67 22 per lineal foot, while Design 1 costs but $65 10; hence, Design 1 costs $2 12 less per lineal foot or about $11 200 less per mile than Design 10. The pedestals are more economical in Design 10 than in Design 1, owing to the greater span length used in the former. The additional cost is due to the great amount of metal required to provide for the longitudinal thrust.

Æsthetics.—Design 10 has probably as much to commend it from an æsthetic point of view as any of the designs under consideration.

Uniformity of Construction.—This design, like Designs 1, 2 and 4, can also be used on the double-track structure without any changes in the columns or cross-girders.

Facility of Manufacture and Erection.—This design is very easy to erect, as there is very little riveting to be done in the field. The stringers rest upon the flaring tops of the columns and require only a few rivets to hold them in place. There would be about the same amount of field riveting to be done in this design as in Design 1. There is considerable curved work in both plates and angles in the details at tops of columns, which details are rather complicated; hence the shopwork will be expensive and unsatisfactory.

From the foregoing facts it is evident that Design 10 offers but few advantages and is also an uneconomical structure.

Design 11, Fig. 22.

Nearly all that has been said in regard to Design 10 applies also to Design 11, the principal difference in the two designs being in the section used for the columns. In Design 11 there are two 15-in. channels strengthened by $3\frac{1}{2}$ x 3-in. 23-lb. angles, and near the top the channels are curved outward, so as to provide bearing for the stringers or longitudinal girders. Experience shows that these curved channels are liable to crack.

The cost of Design 11 is exactly the same as that of Design 10. The same provisions are made for longitudinal thrust, but Design 10 would be easier to manufacture, and would be preferable to Design 11.

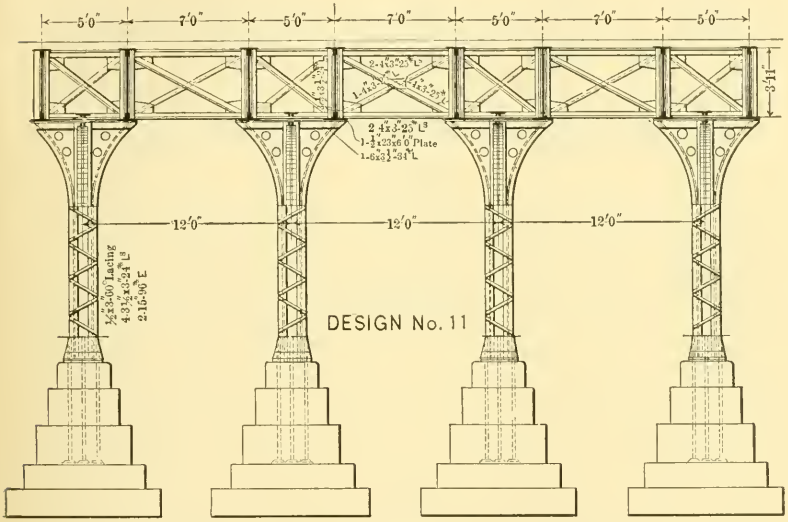


Fig. 22.

Design 12, Fig. 23.

Design 12 is for the alternative route, and is therefore to be placed in the street. Instead of having the columns located in the roadway, as in the Wabash Avenue Extension of the Lake Street Elevated, they will be placed back of the curb lines on the sidewalks, and a heavy cross-girder will span the roadway and support the longitudinal girders, which will be spaced, as in all the other designs, 5 ft. centers, with the two tracks 12 ft. centers. No longitudinal sway bracing can be used, therefore the columns are figured to take up the thrust by bending. The column section will consist of one 15-in. I-beam riveted between two 15-in. channels turned face to face.

Strength.—This design is made very strong, and is thoroughly braced laterally. The columns are each anchored to the pedestals by four anchor bolts which fix their feet, while the tops are fixed by heavy struts extending from the columns to the stringers.

Rigidity.—Owing to the great distance between the columns, transverse to the structure, this design will not be as rigid as Designs 6 and 7, but every precaution has been taken to avoid vibration and deflection. An efficient lateral system has been provided throughout, on tangents as well as on curves, and it will be as rigid a structure as could be expected on this plan.

Economy.—This cannot be called an economical design when compared with the preceding designs for double-track structures, as the

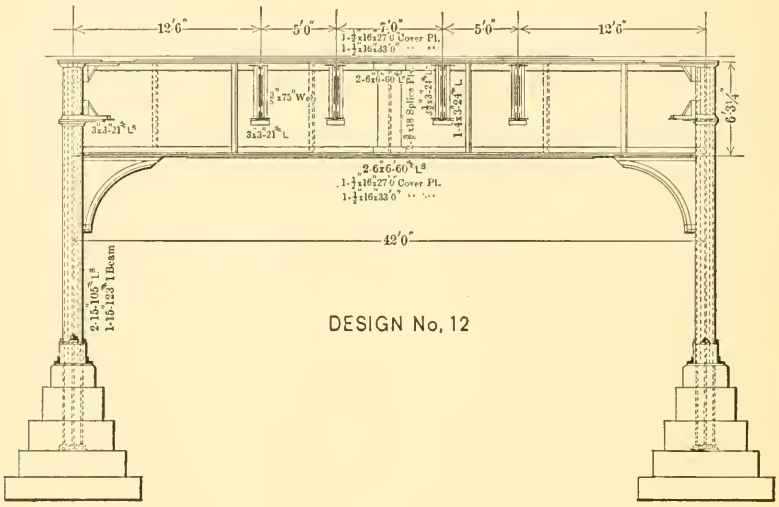


FIG. 23.

total cost per lineal foot amounts to $42, while Design 8 costs but $32 30 per lineal foot. This excessive cost is due to the spacing of the columns and the extra weight of cross-girders occasioned thereby.

Facility of Manufacture and Erection.—This will be a very easy design to manufacture, as it is all straight work; the erection, however, will be much more difficult than that of any of the other double-track structures under consideration, owing to the large number of field rivets to be driven and the great weight of the cross-girders.

Design 13, Fig. 24.

Design 13 is also for the alternative route in case a franchise can be secured permitting the columns to be placed in the roadway. This design is similar to the Wabash Avenue Extension of the Lake

Street Elevated, but plate girders will be used throughout for the stringers. The estimate for Design 13 is based upon the assumption that the columns can be spaced 17 ft. centers on Franklin Street and 22 ft. 8 ins. centers on the remainder of the line.

The average cost of Design 13 would be $36 81 per lineal foot, involving a saving of $5 19 per lineal foot over Design 12, or about $27 400 per mile.

Summary of Cost.

Design.	Weight per lineal foot on tangent.	Weight per lineal foot on curves.	Cost of line per lineal foot.	Cost of line and stations per mile.
1	1 565	1 765	$65 10	$383 728
2	1 565	1 765	65 10	383 728
3	1 590	1 790	64 60	381 088
4	1 700	1 920	66 65	391 912
5	1 750	1 950	67 60	396 928
6	775	875	32 65	210 000
7	775	875	32 65	210 000
8	770	830	32 30	208 544
9	850	960	33 31	213 876
10	1 725	1 950	67 22	394 921
11	1 725	1 950	67 22	394 921
12	1 142	1 182	42 00	267 760
13	916	966	36 81	240 357

In the preceding table there have been assumed four stations to the mile. In the four-track structure one of these is an interior station and the other three are exterior stations, while in the double-track structure all are, of course, exterior stations.

It is in order now to discuss faulty details in existing elevated railroads. This will be done without reference to any road or roads in particular, as the sole object of this discussion is to call attention to important defects in order that they may be avoided in future work.

1.—Insufficiency of Rivets for Connecting Diagonals to Chords of Open-Webbed, Riveted Girders.

This defect is more noticeable in old structures than in later ones, especially as the tendency now-a-days is very properly to substitute plate-girder for open-webbed construction. In many of the older elevated roads there is no connecting plate between the diagonal and the chord, but one flange of each of the angles in the diagonal is riveted directly to the vertical legs of the chord angles. This detail involves the use of either two or four rivets to the connection, which is evidently very bad designing, as there should be more rivets used, even if the diagonal stresses do not call for more on purely theoretical

considerations. Where the theoretical number of rivets is very small, additional rivets should be used for two reasons, viz.: First, one or more of the rivets are liable to be loose, and, second, there is nearly always a torsional moment on each group of rivets owing to eccentric connection.

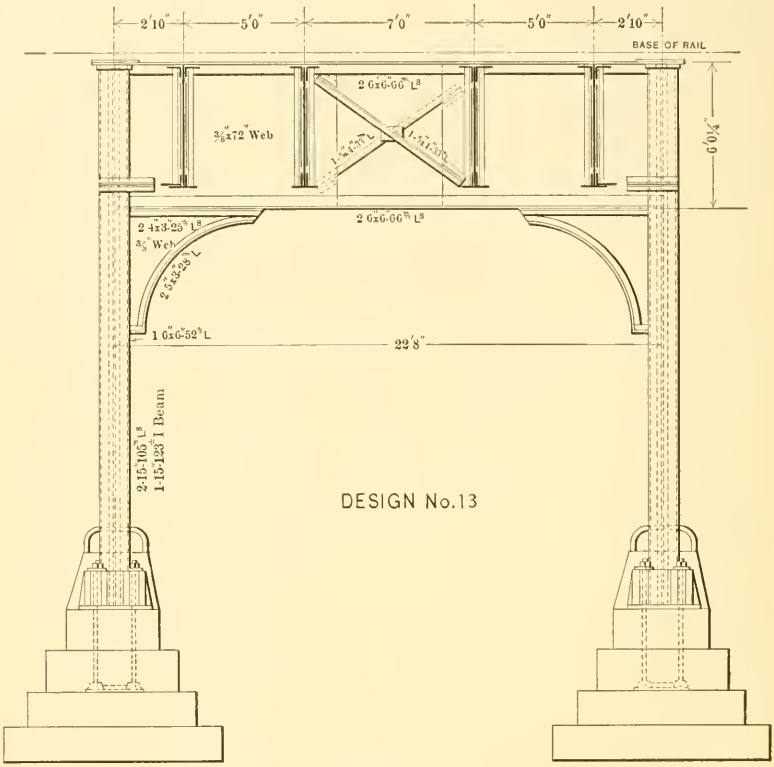


Fig. 24.

2.—Failure to Intersect Diagonals and Chords of Open-Webbed Girders on Gravity Lines.

It is very seldom indeed that the designer even attempts to intersect at a single point all of the gravity lines of members assembling at an apex. The failure to do so involves large secondary stresses, especially in the lighter members. By using connecting plates, it is always practicable to obtain a proper intersection; and it is always better to do this than to try to compensate for the eccentricity by the use of extra metal for the main members.

3.—Failure to Connect Web Angles to Chords by Both Legs.

Some standard bridge specifications stipulate that in case only one leg of an angle be connected, that leg only shall be counted as acting, although this stipulation is generally ignored by the designer working under such specifications. It is seldom, indeed, that both legs are connected. In order to settle the question of the necessity for this requirement, the author has had made, in connection with his Northwestern Elevated work, a series of tests to destruction of full-size members of open-webbed girders, attached in the testing machine as nearly as practicable in the same way as they would be attached in the structure. It was intended to settle by these tests the following points: first, effect of connecting by one leg only; second, effect of eccentric connection; and, third, the ultimate strength of star struts with fixed ends, each of these struts being formed of two angles. As these tests are not yet finished, their results cannot be given here. The principal deduction to be made from the tests thus far completed is that an equal-legged angle riveted by one leg only will develop about 75% of the strength of the entire net section, while a $6 \times 3\frac{1}{2}$-in. angle riveted through the longer leg will develop about 90 per cent. It is therefore more economical for short diagonals to use unequal-legged angles connected by the longer leg than to employ supplementary angles to try to develop the full strength of the piece. In fact, the experiments made up to date indicate that these supplementary angles will not strengthen the diagonal essentially. However, further experiments may show the contrary.

4.—Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.

This neglect is common enough in the older structures, and the fault is a serious one, although the stiffness of the track rails and that of the ties tend to distribute the load and thus reduce the bending.

5.—Insufficient Bracing on Curves.

Too often in the older structures the curved portions of the line are no better braced than are the straight portions. A substantial system

of lateral bracing on curves extending over the entire width of the structure and carried well into the tops of the columns adds greatly to the rigidity of the structure, and, consequently, to the life of the metalwork.

6.—Insufficient Bracing between Adjacent Longitudinal Girders.

The function of the bracing between longitudinal girders is an important one, for it is the first part of the metalwork to resist the sway of trains. Not only should the top flanges of adjacent girders be connected by rigid lateral bracing, but the bottom flanges should be stayed by occasional cross-bracing frames, one of the latter being invariably used at each expansion end of each track.

7.—Pin-Connected Pony Truss Spans and Plate Girders with Unstiffened Top Flanges.

These defective constructions are noticeable in some of the older lines, but, fortunately, not often in the newer.

What the ultimate resistance of the pony-truss structure is no man can tell without testing it to destruction; but in the opinion of most engineers it is much less than it is assumed to be by those designing pony-truss bridges.

8.—Excess of Expansion Joints.

Too many expansion joints in an elevated railroad are nearly as bad as too few. In the former case the metal is overstrained by the vibration induced by the lack of rigidity, while in the latter case it is overstrained by extreme variations of temperature. There are elevated roads in existence with expansion joints at every other bent, and there is one with them at every bent. For long spans there should be expansion provided at every third bent, and for short spans at every fourth bent.

9.—Resting Longitudinal Girders on Top of Cross-Girders Without Riveting Them Effectively Thereto.

This is by no means an uncommon detail, especially in the older structures. It is conducive to vibration, and its only advantages are ease of erection and a cheapening of the work by avoiding field riveting.

10.—Cross-Girders Subjected to Horizontal Bending by Thrust of Trains.

The resistance that can be offered by a cross-girder to horizontal bending is very small; nevertheless, cross-girders are rarely protected from the bending effects of thrusts of trains. What saves these cross-girders from failure is the fact that continuity of the track tends to distribute the thrust over a number of bents. Nevertheless, it is not legitimate to depend on this fact, for, especially on sharp curves, the tendency is to carry the thrust into the ground as directly as possible. In the author's opinion the only proper way to provide for this thrust is to assume that 20% of the greatest live load between two adjacent expansion points will act as a horizontal thrust upon the columns between these two expansion points; and all parts of the metalwork should be proportioned to resist this thrust properly.

By running a strut from the top of each post diagonally to the longitudinal girder at a panel point of its sway bracing, the horizontal thrust is carried directly to the post, and a horizontal bending moment on the cross-girder is thus prevented. Such construction should invariably be used where the conditions require it.

11.—Cutting Off Columns Below the Bottom of Cross-Girders and Resting the Latter Thereon.

This style of construction, which until lately was almost universal, is extremely faulty in that there is no rigidity in the connection, and the column is thus made more or less free-ended at the top.

It has been said that no harm is done to the column by making it free-ended, as it can then spring better when the thrust is applied. Unfortunately this reasoning is fallacious, because the few unfortunate rivets which connect the bottom of the cross-girder to the top of the column tend to produce a fixed end, and are, in consequence, racked excessively by the thrust of the train. In all cases the column should extend to the top of the cross-girder and should be riveted to it in the most effective manner practicable.

12.—Paltry Brackets Connecting Cross-Girders to Columns.

Brackets are often seen composed of a couple of little angles and attached at their ends by two or three rivets. Such brackets are merely an aggravation, and are sure to work loose sooner or later. Although

it is impracticable to compute the stresses in this detail, nevertheless, good judgment will dictate the use of solid webbed brackets riveted rigidly to both cross-girder and column so as to stiffen the latter and check the transverse vibration from passing trains.

13.—Proportioning Columns for Direct Live and Dead Loads and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.

The practical effects of this fault can be seen to best advantage by standing on one of the high platforms of one of the elevated railroads in New York City. The vibration, by no means small, from an approaching train can be felt when it is yet at a great distance. Some may claim that this vibration is not injurious; but they are certainly wrong, for what does it matter so far as the stress in the column is concerned whether the deflection be caused by vibration or by a statically applied transverse load, so long as the amount of the deflection is the same in both cases. It takes metal, and considerable of it, to make columns strong enough to resist bending properly, and a sufficient amount should be used to attain this end.

14.—Omission of Diaphragm Webs in Columns Subjected to Bending.

If the diaphragm web be omitted in such a column, reliance must be placed on the lacing to carry the horizontal thrust from top to bottom. But even if the lacing figure strong enough to carry it, which is unusual, it is wrong to assume it so, for the reason that one loose rivet connecting the lacing bars will prevent the whole system from acting, as will also a lacing bar that is bent out of line. Decidedly every column that acts as a beam also should have solid webs at right angles to each other.

15.—Ineffective Anchorages.

On account of both rigidity and strength every column ought to be anchored so firmly to the pedestal that failure by overturning or rupture would not occur in the neighborhood of the foot, if the bent were tested to destruction. The flimsiness of the ordinary column-foot connection is beyond description.

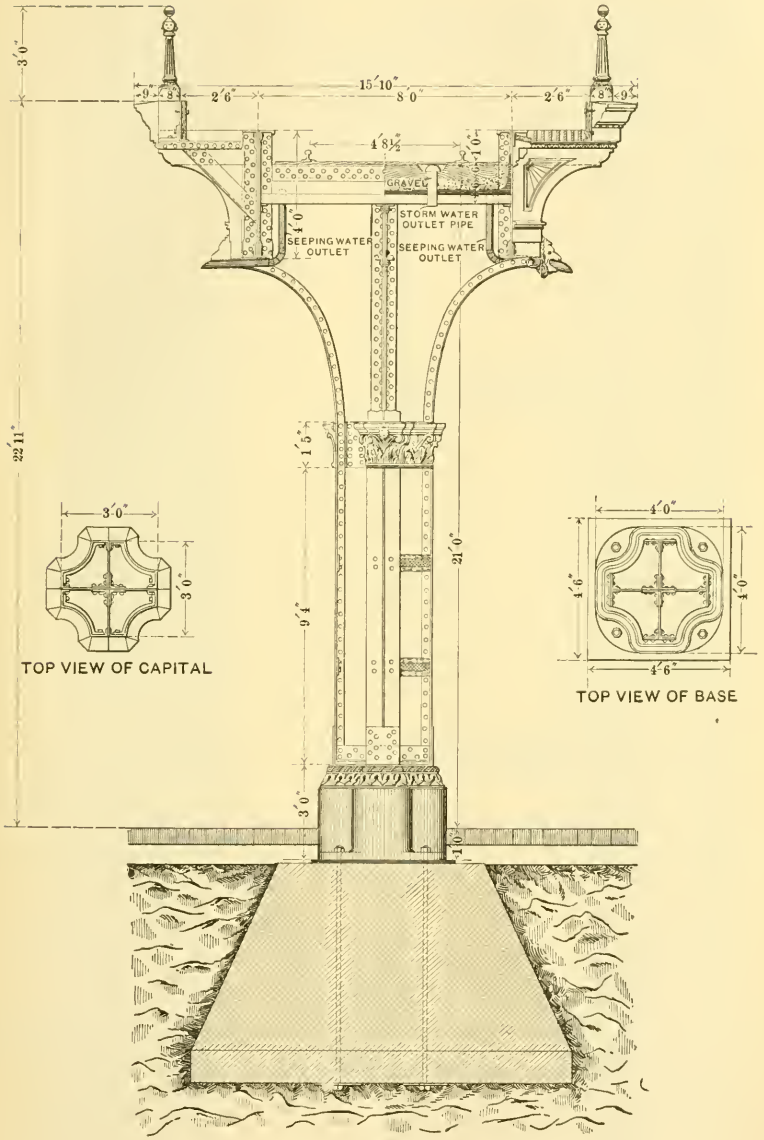

3′0″
9″
8″
2′6″
15′10″
8′0″
2′6″
8″
9″
4′8½″
2″
1′0″
GRAVEL
4′0″
SEEPING WATER OUTLET
STORM WATER OUTLET PIPE
SEEPING WATER OUTLET
22′11″
1′5″
21′0″
9′4″
3′0″
1′0″
3′0″
3′0″
TOP VIEW OF CAPITAL
4′0″
4′6″
4′0″
4′6″
TOP VIEW OF BASE

Fig. 25.

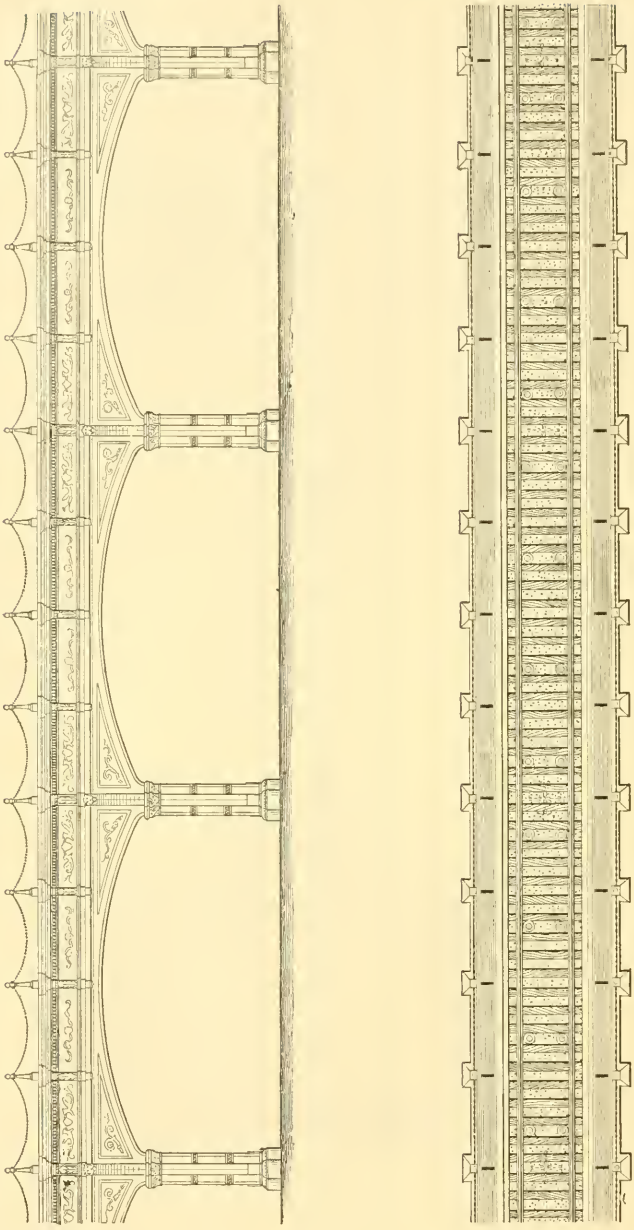


FIG. 26.

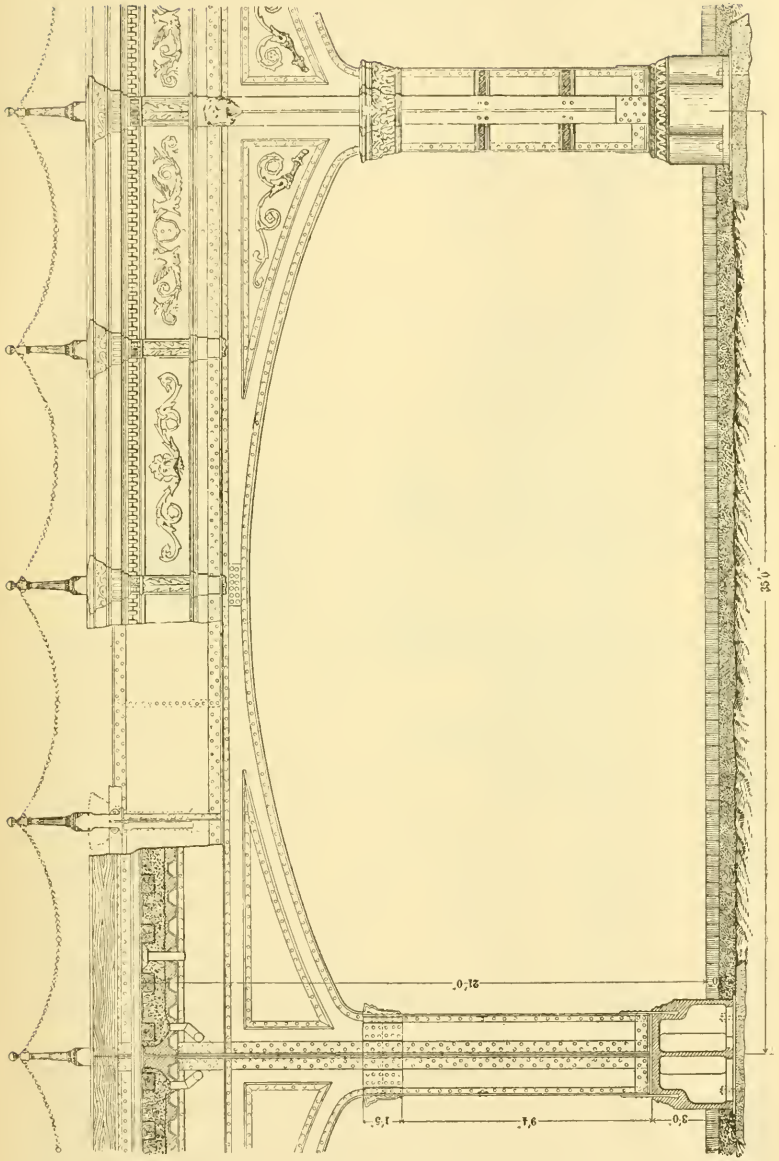


FIG. 27.

16.—Column Feet Surrounded by and Filled with Dirt and Moisture.

The condition of the average column foot is simply deplorable. This is caused by failing to raise it so high above the street as to prevent dirt from piling around it, and by omitting to fill its boxed spaces with concrete. When rusting at a column foot is once well started, it is almost impossible to stop it from eating up the metal rapidly.

17.—Insufficient Bases for Pedestals.

False ideas of economy on the part of projectors and indifference on the part of some unscrupulous contractors occasionally cause the use of pedestal bases altogether too small for the loads that come upon them, especially where the bearing capacity of the soil is low. The result is sunken pedestals and cracked metalwork. In figuring the pressure on the base of the pedestals it is not sufficient to recognize only the direct live and dead loads, but it is necessary also to compute the additional unequal intensities of loading caused by both longitudinal and transverse thrusts.

Æsthetics.

In relation to æsthetics in the designing and construction of elevated railroads something may be said, although but little has been done. The extra cost of decorating an elevated structure is certainly considerable, and on this account projectors are chary of attempting to do more than make the work strong and durable, preferring to let the appearance take care of itself. Notwithstanding this, the careful designer can generally manage to make his construction more or less sightly without adding materially to the expense. This the author attempted to do in both the Northwestern and the Loop. It is for others to say whether he has succeeded or not. At the Diversey Street and Sheridan Road crossings of the Northwestern Elevated some extra ornamentation was compulsory, so it was put in at increased expense; but elsewhere no extra money was expended on appearance.

Some time before the Northwestern Elevated was contemplated, and while several parties were trying to obtain concessions for a down-town loop, the author made a special study of an æsthetic type of structure for this locality, in which the consideration of expense cut no figure. The result of his studies is shown in Figs. 25 to 29, inclusive, Fig. 25

being a cross-section of such a structure, Fig. 26 a plan and elevation of a single-track railroad, Fig. 27 a side elevation showing some of the details of construction, Fig. 28 a cross-section of a street with a

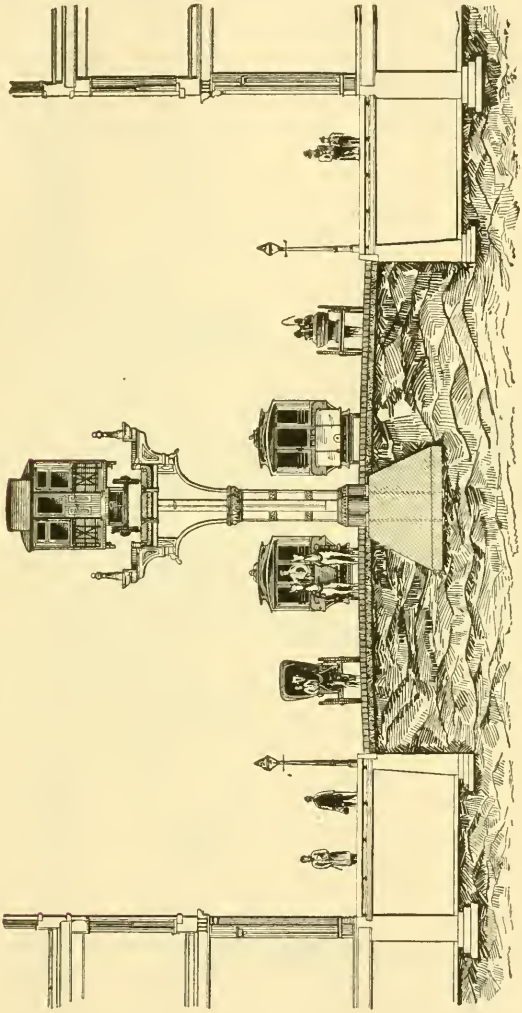


FIG. 28.

road of this type, and Fig. 29 a cross-section of the same road with a double-track elevated railroad. These designs involved not only appearance, but comparatively noiseless operation and freedom from

dripping of water on the people beneath the structure. Although no line was built according to these drawings, they have, notwithstanding, proved of practical utility in several ways; and the author now

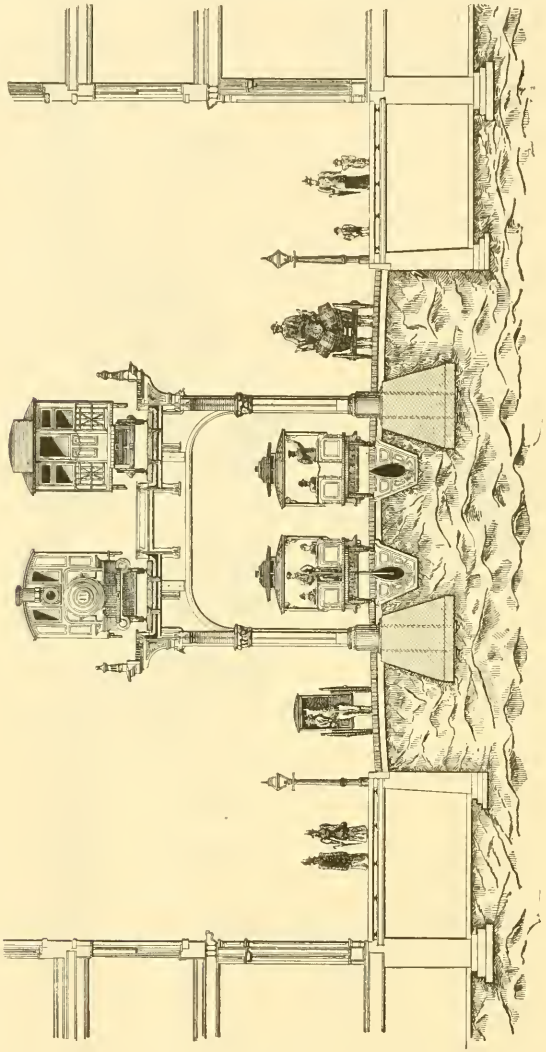


Fig. 29.

offers them to the engineering profession as his idea of what an elevated railroad for a large city should be where expense is no object and where appearance is the great desideratum.

DISCUSSION.

O. F. Nichols, M. Am. Soc. C. E.—Elevated railways are continuous bridges on which the loads are lighter but more frequently applied than on ordinary bridges. No special inspiration is required for their design. If they are built strong enough; if, since they cannot be made beautiful, it is possible to avoid making them ugly; if they are built to suit public convenience and at relatively low cost—then about all has been accomplished that lies in the mind of man to do for the ordinary elevated railways. Mr. Nichols.

It seems that much of the structure treated of in the paper is for four-track service and some of it on private property. The four-track system, like the loop system, is theoretically perfect, and yet seldom used in practice. New York City is probably the only place in which a four-track elevated railway would be bound to be successful, and where four columns under four tracks would be necessary. Designs 3, 6, 7, 8, 9 and 13 are all quite familiar as having been considered, in their essential features, in the studies made for the Suburban Rapid Transit Company of New York City in 1886-87.

For a railway on private property and where the space under the rails cannot be utilized for business purposes, as in cities like Chicago and New York, it seems the better way to build a viaduct; to surround the plot with a retaining wall of concrete and fill in with dirt; then place girders over the cross streets and lay the rails. An estimate made in 1888 showed that such a railway could be built cheaper than the structures considered in the paper.

There have been a number of types of foundation for elevated railways. In no place has the peculiar aversion to concrete been more notable, and in few instances has its use been more satisfactory. The several types of foundation used on the Brooklyn Elevated Railroad are shown in Fig. 30. The reduction in cost, corresponding with the changes in form and material, has been notable, passing from $190 each in 1885 to less than $90 in 1893. It will be seen that the type D, adopted early in 1892, is the one copied in the studies now under discussion. The author has, however, missed the true spirit of the design, and, misled by his column theory, has misused this really serviceable and economical foundation.

In securing the column to the foundation the author repeats, he says, the fastening he used in Sioux City in 1891; he certainly duplicates the fastening designed for the Union Depot shed in St. Louis.

If one were anchoring to solid rock or to massive foundations and resisting much greater stresses, these lugs might be necessary, but when, as in the sketches, 40 000 lbs. of tensile strength in anchor bolts is opposed to 13 000 lbs. of concrete, and the bolts are doubled for assumed extra stress, while the concrete mass remains the same, the

Mr. Nichols. lugs have a questionable value. This fastening keeps the bolts too near the center of the foundation, makes the resistance to rocking depend too much on the stress in the bolts, and is needlessly awkward and expensive.

A striking feature of the designs in the paper is the distribution of material in the columns themselves, in their connections and in the lateral bracing, and in the complex machinations necessary to endeavor to utilize this material. Indeed a series of troubles arises from the opinion that "20% of the greatest live load between two expansion points will act as a horizontal thrust upon the columns between these expansion points." This is pure fiction; it is not even empirical. There is nothing to justify it. Even the emergency stops in the air-brake tests do not give much more than 10% of retardation, measured at the rails. If the trains were skidded without wheels, the retardation would hardly reach the figure named. The dynamometer rarely shows more than 4 000 lbs. as the pull necessary to start an elevated train, and little, if any more, is needed to stop it. Then this thrust is not concentrated or limited in its action to a few feet of structure; it is spread through the rails and track system and structure generally to the next curve. The actions of the several trains counteract each other to a certain extent, and the net effect may possibly correspond to a pull or thrust at the rails equal to 3% of the total moving load on a half mile of structure and would be distributed over about a hundred columns.

There is a phenomenal continuity in these structures. It is impossible to close up an expansion joint except by expansion, which never amounts to as much as the ordinary theoretical requirements, because provision is made for excessive ranges of temperature. Owing to the continuity of the structure there is, in practice, very little lateral stress on the cross-girders, even in extreme cases and on curves. The older builders fixed the base of the column, and left the top free to vibrate; the more recent structures have the base of the column held and the top firmly fixed to the transverse girder; as a consequence, the stiffness of the column is brought fully into action and is then generally sufficient to resist the slight tendency to vibration. The recent structures do not vibrate, and have been likened to a common table, in which the legs are securely fastened to the top.

The entire effect of the extension of the lateral system beyond the longitudinal girders is to fix the columns partially at the top. Unfortunately the sketches do not give a clear idea of the details of construction; it would seem, however, as if none of the connections of the columns to the girders are either very simple or thoroughly effective.

No one has ever made a very satisfactory column from I-beams. The Z-bar is somewhat better for column construction, but both sections are unsatisfactory when it comes to connections with girders

Mr. Nichols.

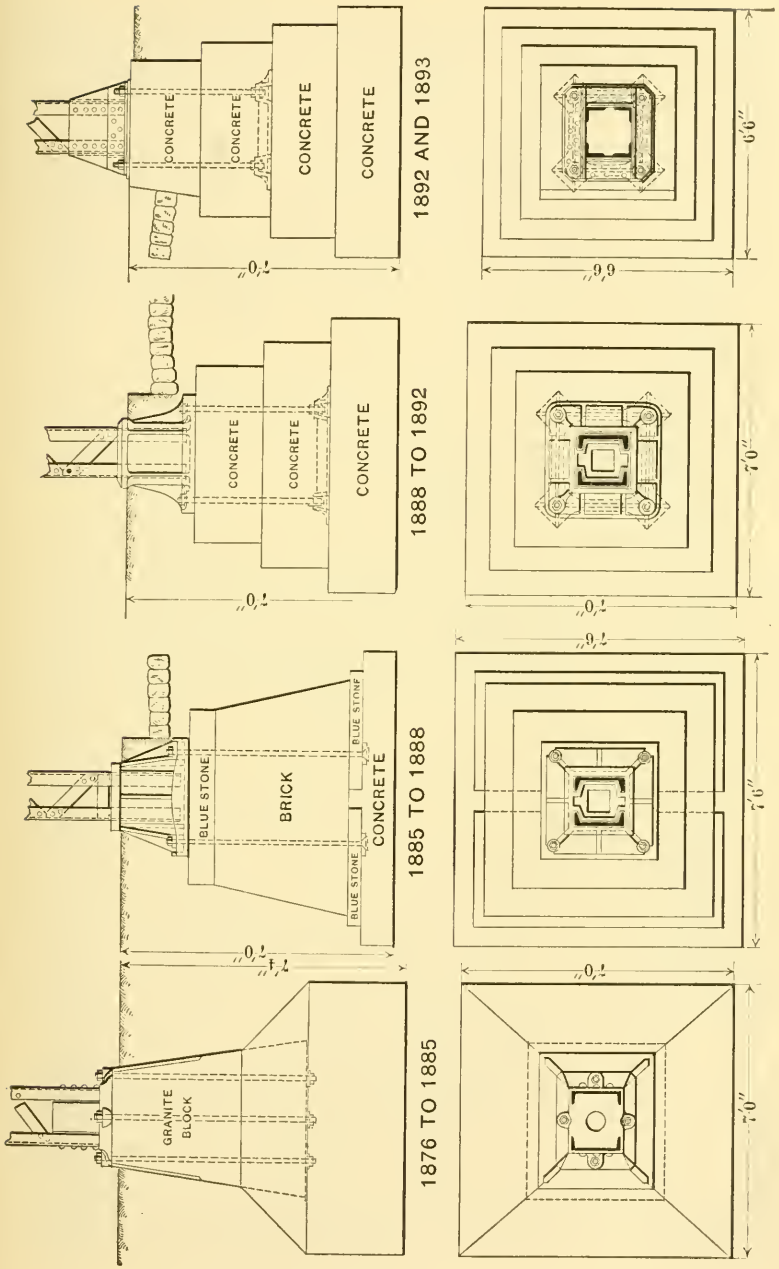


Fig. 30.

Mr. Nichols. or with column feet. The author's condemnation of the straight brace and his unqualified approval of the curved bracket are somewhat irrational and will not be generally approved. The curved bracket is unsatisfactory, because it professes so much and accomplishes so little; it is ugly, and, unless very heavy, it is ineffective.

Far too much stress is laid on the necessity for a web plate in a column, especially in a direction transverse to the axis of the structure. It is unnecessary to consider wind pressure, as such, in connection with an elevated railway of the ordinary height. There are, of course, lateral stresses to meet. They are, however, generally quite indeterminate, and may be fully provided for by simply fixing the column to the cross-girder at the top, and providing a double-riveted lacing of the column in this, lateral direction.

It certainly seems strange that Designs 12 and 13 should have much larger column sections than Design 3, which may easily have twice as great a load. This all follows quite logically, however, from the use of the column theory prescribed in the paper. It would be interesting to see, and weigh, the lateral brace for Design 3, when properly made to satisfy this column theory.

The expansion pocket (Figs. 8 and 9) has nearly all the defects of the old strap pocket of a generation ago, and is, constructively, a corruption of a pocket designed by Theodore Cooper, M. Am. Soc. C. E., in 1886, for the Suburban Rapid Transit Company, and since used on the Brooklyn road, with a reduction of the length of the lever arm of the load. Expansion joints need not be placed nearer together than 200 to 250 ft.; the latter distance was used latterly in Brooklyn, the joints occurring at the middle of every city block. These structures do not reach the high ranges of temperature generally assumed, and rarely expand and contract more than $\frac{1}{2}$ in. in 100 ft., and often not so much.

It is important that the cost of elevated structures should be kept down, although there is a possibility of exaggerating the importance of this matter. For the New York City roads, the interest on the present cost of stronger structures would constitute less than 15% of all annual expenditures. The problem is to get the best effect for the least money, *i. e.*, for the least weight of structure. It has been well said that existing elevated structures have plenty of material in them, but not rightly distributed. In this respect, the studies of the paper mark but slight advance over previous practice.

One of the most economical structures ever built was the stem line of the Suburban Rapid Transit Company. It was located on private property except at street crossings, and had but two tracks, although these were located with reference to the possible addition of two more. Masonry piers were used on the private property, instead of columns. Continuity of structures was not necessary or desirable; the longitudinal girders rested on iron plates, placed on the granite

Mr. Nichols.

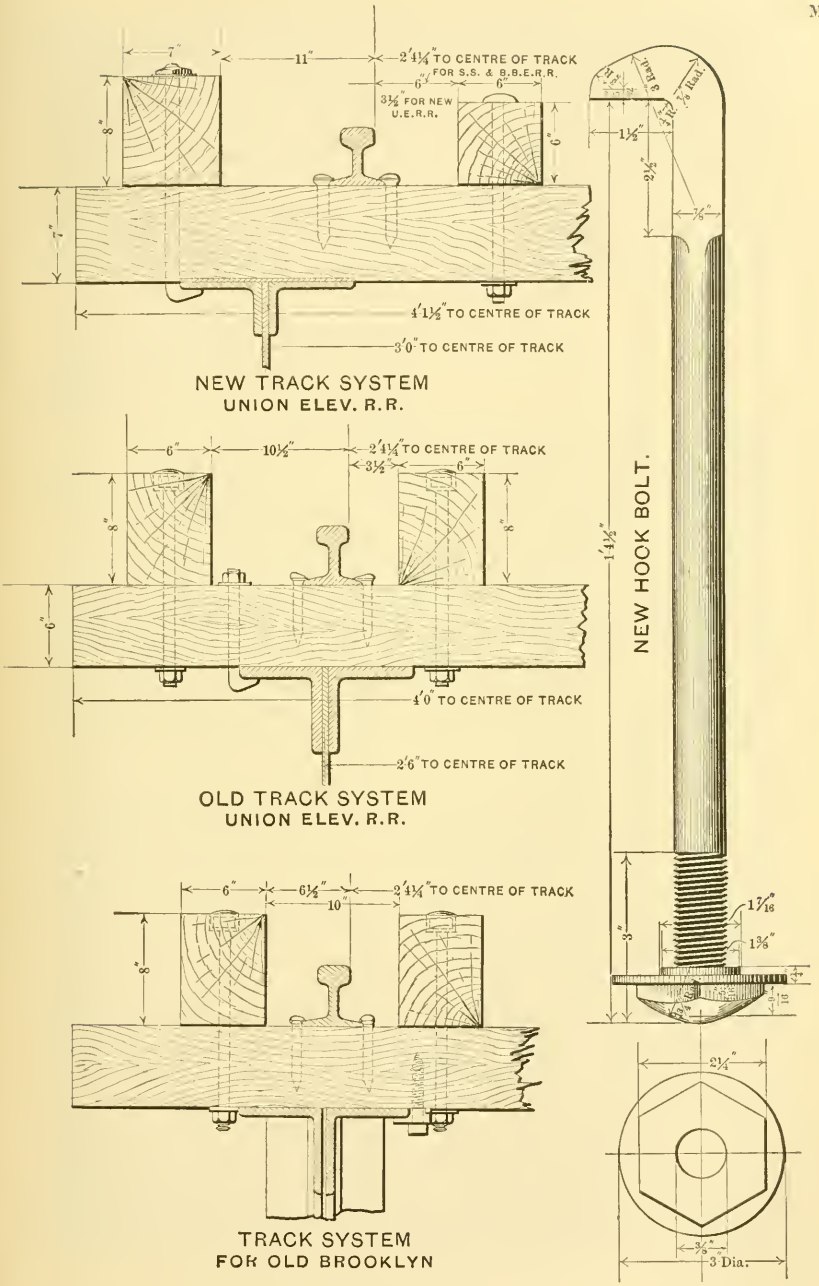


FIG. 31.

Mr. Nichols. coping of the brick piers. One end of each girder was fixed, the other slotted over ¾-in. bolts set in the coping. There was absolutely no vibration; the bents were substantial, imperishable and economical; the cost of the structure for double track was about $35, and a type was designed estimated to cost $30 per lineal foot. The loading was nearly twice that provided for in the paper under discussion.

The following approximate data for the Brooklyn Elevated Railroad is based on actual construction rather than on studies, and excludes siding, yards, water, coaling and interlocking plant, and all stations, other than noted, and reduces the cost of structure to 3 cents per pound.

	Old Brooklyn Lines.	Later Union Lines.	Sea-Side Lines.	Fulton Avenue Extension.
Average length of spans	44.7 ft.	50.9 ft.	52.5 ft.	
Weight of structure per lineal foot	870 lbs.	1 050 lbs.	1 130 lbs.	950 lbs.
Cost of structure per lineal foot, including foundations	$34 70	$36 50	$37 40	$32 00
Cost per mile, including passenger stations	.....	308 000 00	286 950 00	213 900 00
Percentage of cost of bents to cost of spans	75%	69%	65%	

The length of span is about the same as that recommended by the author, but the percentage of cost of bent to cost of span is much less. If the "true theory of economy" is correct, about 30% should be added to the cost of these Brooklyn bents, and since this must be put into the metal, the foundations being the same, it would add about 12 000 lbs. of metal to these bents, which has, heretofore, been considered unnecessary.

The track system of the Manhattan Railway seems to have been accepted without much question. This system illustrates the persistency of minor errors and the ability of individuals to perpetuate their idiosyncrasies. The ties are not thick enough, nor is the outer guard-rail wide enough. The inner guard-rail is of little use in new structures, other than to space the ties and to give a sort of moral confidence to the timid, and these are its principal uses in the recent Brooklyn lines. If the only objection to projecting nuts was the danger of tripping one up in walking over the track, they would not be so studiously avoided or yield so easily to the cuspidors formed by the Manhattan cups. Fig. 31 illustrates the principal types of track system used on the Brooklyn lines.

The beveled ties provided for in the studies of the paper were first used on the Brooklyn lines in 1889, and had, no doubt, been used before that time, if not on elevated railways. They are theoretically all right, but the track-men prefer the old wedge block as more convenient to handle and reset. The author apologizes for a compromise

between theory and practice in using low elevations of the outer rail on curves, and says, "experience in operation alone will tell whether the decision of the company's engineers in the matter is correct." There need be no uncertainty on this score; these low elevations have been in use on all elevated railways from the beginning. There is no compromise with theory, since the lower elevations correspond with the slower speed absolutely required on sharp curves to avoid unseating the passengers. Mr. Nichols.

It is unfortunate that the details of the longitudinal girders and their connections are not given in the paper, as there are indications that close adherence to the scholastic methods has led to the retention of some of the antique errors of girder construction.

The simpler an elevated railway can be built, the better; the smaller the number of parts and the simpler the shape of these parts, the more satisfactory will the work be. No attempt at ornamentation should be tolerated, and the illustrations in the paper show this to be true. Ornament, to be good, must be necessary, and must be true. These conditions are not satisfied on elevated railways, except in the most rigorous simplicity of treatment.

The columns, in the æsthetic studies, are very large, and the spans inconveniently short. The arch span has no practical value. It does nothing that could not be better done without it; it is, in consequence, insincere and misleading and cannot be justified. It is intended to hide the girder, which really does the work, and is therefore a deluding member.

The æsthetic structure does not seem to require the heavy holding-down lugs and bolts of Designs 1 to 13; it will, perhaps, hold itself down. Here is, indeed, a structure, Figs. 27 and 29, which does not require holding-down bolts; which could, in fact, be skidded along over thick ice on its feet without falling, simply because its legs are stiff enough and are well fastened to its body. In this respect it sustains the recent practice in the East, if it does not fully satisfy the theories of the paper.

Henry B. Seaman, M. Am. Soc. C. E.—In studying the requirements and the necessary expedients of an engineering problem, and in making the usual examination and research for precedent, many features will be found which indicate the influence of extraneous conditions over which the engineer has no control. This may be considered to have been the cause of such details in elevated structures as the use of flat plates for the main compression diagonals of lattice girders, or the construction of cross-girders with inclined end-posts, and with no other column connection than that afforded by an iron casting; but, though such details may, indeed, teach how not to do it, to say there are no other lessons to be learned from these structures is to forget that when first constructed some twenty years ago, Mr. Seaman

Mr. Seaman. they were unprecedented, and their better and more successful features have become so blended with general practice that even the examining engineer may fail to recognize the very source of his better information. These elevated roads, after twenty years of service, under loads exceeding those for which they were designed, show no indication of such deterioration as would justify the prediction of the author that they will eventually be reconstructed because of their faulty details.

There are several features of these elevated roads, which are worthy of consideration by those engaged in the most recent practice, and one of these is the effect of the longitudinal thrust of stopping trains. The use of the coefficient of 20% is extreme, even on a purely theoretical basis, as an examination of the tests of efficiency of air brakes will show. These tests, made under exceptionally favorable circumstances, show a resistance of about 15%, and when it is considered that the compact wooden floor system distributes such force indefinitely, it may be doubted if the resulting strains are of any considerable importance. Vibration must occur so long as iron has elasticity, but that such vibrations produce excessive strains, or in any way injure the structure, is not indicated by experience. If the vibrations are unpleasant, the remedy is to build stations and platforms upon separate foundations, with no connection to the main girders.

The speaker had already discussed the use of steel.* Though the exigencies of manufacture have practically eliminated the general use of fibrous wrought iron, it is reassuring to note the gradual progress toward a soft steel on account of its greater uniformity and freedom from hard spots. It seems to be the growing opinion among engineers, that the use of high or medium steel so increases the contingencies of failure, due to hardness, that a decrease of section is not warranted.

The shop coat of paint should, in the speaker's judgment, be one which will not conceal defects of manufacture, and for that reason he advocates the use of pure boiled linseed oil; but for a permanent coat of paint, there is probably nothing much better than red lead, unless experience should prove that carbon paints afford better protection against locomotive fumes. Some time ago, while examining a railroad bridge which had oxide of iron paint on compression members, and lead paint on tension members, both applied about four years previously by the same painters, the oxide of iron showed heavy scales and rust, while the lead was still in perfect condition.

In rail sections it would hardly seem necessary to go beyond those recommended by the Committee of this Society, which was composed of members of special experience, and whose report was the result of extended deliberation.

* *Transactions*, Vol. xxvi, p. 230.

Mr. Seaman.

The author's device for securing a truly fixed base of column is a good one, but the cast-iron bases of the New York roads have been entirely efficient, and in these cases the anchor bolts extend nearly to the base of foundations, instead of half way through, as the author shows. The detail of expansion joint is likewise thoroughly scientific, and a similar device has been extensively used in the vicinity of New York with very satisfactory results. The old style of pocket, formed merely of a bent plate, has, at times, proved weak at the bend.

The estimates of cost presented by the author are extremely interesting and valuable, but should not be considered with undue refinement, without the details on which they are based. For instance, Designs 6 and 7 are stated to be alike, except the additional brackets on No. 6, yet the estimate for each is the same; also, Design 8 has cross-girder strains and brackets, yet it is said to be less expensive than No. 7. Again, in the comparison of plans, he places the four-column structure on the same basis as that with two columns, though he does not state whether or not he has considered the fact that the four-column structure would receive its maximum column load from each train that passes over it, while the two-column structure would practically never receive such strain.

While his brother engineers may differ from him in a number of details, it is not intended to detract from those main features of the author's paper which are beyond criticism, and for the presentation of which all are indebted. He is likewise to be congratulated upon receiving the endorsement which has enabled him thus to adhere to the most advanced practice.

Mr. Clarke.

T. C. Clarke, Past-President Am. Soc. C. E.—The author gives a list of sixteen "essentials" to good elevated railway construction. Having laid down the law, he went on a tour of observation to see if it had been followed. The results were unsatisfactory. He went believing "that the methods in vogue for constructing elevated railways were radically wrong," and came back having accumulated "a great mass of information showing how not to do it." If he had carefully examined and correctly reported the condition of the Second Avenue structure of the Manhattan Elevated Railway of New York, he must have admitted that it conforms in general design to all of his sixteen "essentials," although in detail there are many differences.

The speaker took direct issue with the author's sweeping statement, and maintained that this structure, although designed twenty years ago, is not radically wrong, and has by its performance shown that it is not. The columns are of Phœnix section, but stronger than the section designed by the author. The foundations and their attachment to the columns are much better calculated to resist bending strains on the columns, and as there are none, it is perfectly proper to stop the columns at the bases of the cross-girders. That they are

Mr. Clarke. none the worse for this is evident from the fact that there is no perceptible vibration for approaching trains, whatever may be the case elsewhere. The Second Avenue girders have "no connecting plates between the diagonals and chords" and have fewer rivets than the author believes to be proper, but it is a matter of fact that after seventeen years' service under a heavy traffic there are few or no loose rivets.

By the courtesy of Mr. Fransioli, General Manager, and Mr. Waterhouse, Chief Engineer of the Manhattan Elevated, the speaker was able to give the following interesting statistics as to the Second Avenue structure:

Age, 17 years. Length, 7.4 miles. Total cost of repairs to structure, not including track and painting, $40 613 23; per year, $2 390; per mile per year, $319. Cost of repairs per ton of structural iron in 17 years, $1 39, which is about 2% of the original cost. The total tonnage passing over this structure in 17 years is 252 356 693 tons.

Practical men would call this good design and good construction, however it may be criticised.

The expansion joints and the entire floor system of the Second Avenue structure have been closely imitated by the author, and the speaker was able to agree with him so far. He also agreed with the author where he says that holes in riveted work should be punched smaller than the diameter of rivets, and reamed to a greater diameter. Either this or drilling is essential to first-class work. The speaker specifies it himself for swing-bridges and long spans. Whether it should be insisted upon for elevated railway work he has some doubts; it would, perhaps, be better to put the extra cost of reaming into increased quantity of metal.

The Second Avenue structure was not reamed, but it is unusually massive. Its weight per foot for two tracks, the posts and cross-girders being designed for four, is equal to that of the author's four-track structures. It is believed that its durability is due in a great measure to the low strains and large areas of metal, as well as good workmanship.

Mr. Crehore. William W. Crehore, Assoc. M. Am. Soc. C. E.—The author's statement as to the importance of good details and workmanship in elevated railroad structures is certainly commendable. There may be honest differences of opinion among engineers as to the comparative merits of two or more styles of detail to perform a given duty, but there are certain well-recognized principles which have been proved by experiment and experience to be fundamental in connecting and detailing the parts of a structure so that the full strength of each member is available when needed. That these principles either were not thoroughly understood or were not deemed of sufficient importance by the builders of elevated railroads ten or twenty years ago is very much

in evidence in New York. The speaker had no more intimate knowledge of the Manhattan elevated structure's condition than any one may obtain by riding over it or looking at it from the street, but enough is evident to show that the structure could be very much improved upon if rebuilt. Although the rolling stock now used is no heavier than was provided for by the designers, yet the live load is now a maximum, the wear and tear is continuous, and the speed of trains has been much increased, notably on curves. Then, too, the improvements in the air-brake during the last fifteen years have caused a substantial increase in the traction load. It was the opinion of the speaker that under these conditions no amount of patching can prevent a gradual decline in the factor of safety of the structure, and without wishing to arouse any undue apprehension, one might reasonably seek to know why, in a city that gives special attention to all other building construction, whose insurance companies inspect carefully and regularly the elevators in the tall buildings, and whose vigilance for the health and safety of the people is so practical and thorough in other directions, the elevated railroad structure which carries 500 000 people a day should be left, with no check except the occasional superficial inspection of the State Railroad Commissioners, entirely to the watchfulness of its own management, which in other matters is known to be not too particular. Mr. Crehore.

It will be argued and figures might be produced to show that the elevated railroads in New York have been remarkably free from accidents, having carried an enormous traffic during the last twenty years with practically absolute safety; all of which is true, being due partly to the very efficient handling of trains, and partly to the fact that the factor of safety of the structure is not yet used up. A chain is no stronger than its weakest link; the factor of safety of a structure is no greater than that of its weakest member or its weakest detail. A structure which is subjected to continual vibration and is never painted must of necessity be wearing out. It therefore becomes a matter of great interest to all who are directly concerned to know how nearly worn out the individual members and details of the Manhattan Elevated Railroad structure are.

CORRESPONDENCE.

Mr. Bouscaren. G. BOUSCAREN, M. Am. Soc. C. E.—Two points are brought out by the author which are specially worthy of discussion, viz., the selection of the grade of steel most appropriate to the class of structure under consideration and the desirability of a more extensive application of reaming in riveted work.

The denomination of medium steel generally implies a degree of hardness consistent with an ultimate strength of from 60 000 to 70 000 lbs. per square inch, with a ductility measured by an elongation of about 25% in 8 ins. The corresponding figures for soft steel are generally from 50 000 to 60 000 lbs. per square inch, and about 30% elongation.

Soft steel is a material eminently tough and ductile, the progress made in its manufacture leaves little to be desired in regard to uniformity in the qualities of products, and commands confidence in its ability to resist a considerable amount of rough treatment. It is manifestly superior to iron in most respects, and is rapidly taking its place in ship-building and boiler-making; it is without question well adapted to structures exposed to considerable vibration and impact, such as the deck members of railroad bridges in general, and all members of short-span elevated railroads in particular. The same degree of uniformity in quality cannot be claimed for medium steel at the present time; it may be obtained occasionally, but never with the same degree of certainty. Besides being a harder and less ductile material, medium steel is liable to extra hardness and brittleness in spots. Until it can be treated on the same footing as soft steel in point of uniformity, its use in the riveted members where exposed to sudden variations of stress, or to shocks incident to derailments or collision, will not afford the same degree of security as that of the softer metal. The examination of a railroad bridge fallen under a passenger train, presumably by the work of wreckers, has recently confirmed the writer in his views as to the use of medium steel in deck members. A notable feature of the wreck was a 60-ft. steel plate girder standing almost vertical with one end about 3 ft. in the ground. The only apparent injury to the girder besides the bent lateral angles at the end was in the bottom flanges, two of the four flange angles being cracked squarely across without any other deformation.

Steel of good quality is made by both the acid and basic process, the only marked point of difference seems to be that a lower content in phosphorus is practicable for basic steel than is the case for acid steel. Phosphorus being admittedly an objectionable element in steel, this consideration should seem to settle the question in favor of basic steel.

The writer is in hearty accord with the author in what he says in

regard to the desirability of reaming rivet holes in all kinds of material. It is a universal practice to specify that all rivet holes should match exactly and be of the exact diameter required for the hot rivets. There is no difference of opinion as to the importance of these conditions to the good quality of the work. Every one knows that they cannot be secured without reaming, yet the stipulation as to reaming is generally omitted to save cost. It seems to be one of those instances of puerile self-deception where the engineer, unconsciously, perhaps, seeks to obtain a certain desirable result without paying for it. It is hardly necessary to add that such attempts are generally failures. Every one will also admit that punching is a brutal operation, which seriously injures the metal, be it iron or steel, within a certain distance from the shearing surface. If flaws are objectionable in the body of a plate, they certainly are more so in the bearing surfaces through which all stresses are transmitted. Under the old assumption attributing the resistance of a riveted joint to the friction between the plates, developed by the contraction of the rivets, it was a matter of little importance whether the rivets completely filled the holes or not, and punched holes answered the purpose well enough, but they are inconsistent with modern practice, where rivets are treated as pins. Mr. Bouscaren.

The superiority of reamed work is no longer a matter for speculation. Carefully made tests at the Watertown Arsenal as far back as 1882 showed that it could be depended upon for a gain in strength of about 15 per cent. This result has been repeatedly confirmed by later experiments. As the matter now stands, it is simply a question between good work and inferior work, and whether the extra cost of reaming is worth the additional security implied in the greater strength and uniformity of the work. These advantages acquire a special importance in short spans and decks of railroad bridges.

The use of Portland cement in the concrete for the substructure is a wise provision, especially for the upper part of the pedestals exposed to severe stresses and weather.

In view of the fact that the columns are expected to act as cantilevers anchored to the pedestals, and to resist by bending all horizontal forces arising from curvature, from the wind, and from changes of temperature, it would be interesting to know the maximum degree of temperature, the wind pressure assumed per square foot, the speed of trains assumed on curves, the maximum range of temperature from the initial position where there is no temperature stress, and whether any provision is made for easements at the ends of curves. If such provision is not made, a considerable percentage should be added to the centrifugal force for impact. It would also be of interest to know the units of working stress adopted for the different parts of the structure, and in particular for the columns with the combination of all forces acting together.

Mr. Rousseau. H. H. Rousseau, Jun. Am. Soc. C. E.—In regard to the reaming of holes for shop rivets in soft or even medium steel, the writer believes that due consideration should be given to the average number of component pieces the rivets pass through, to the amount of wear and tear the structure has to withstand, and to the financial resources of the purchaser, before arriving at a decision in any particular case. If the benefit of removing, by reaming, material possibly injured is waived, the question becomes reduced to ensuring sufficient bearing area for the rivets in the most economical, and at the same time a satisfactory, manner. The proposition is not that rivets in unreamed holes have no value, but what is a safe and proper value to give them. The question is not one of vital importance to the safety and stability of the structure, being only to establish the comparative value of a rivet driven in a reamed hole $\frac{1}{16}$ in. larger than the cold rivet, and one driven in a punched hole, the mean diameter of which, according to general practice, is $\frac{3}{32}$ in. larger than the diameter of the cold rivet. Justly or unjustly, no distinction is now made between the two, and, at present, the purchaser has only a choice between unreamed work, which is condemned on account of the deviation of punching from mathematical precision, and upheld on account of its cheapness, and the reamed work of admittedly superior workmanship and higher cost, the rivet values being taken the same for both. If a relation can be once established between the two, then by decreasing the number of rivets for reamed work, the two classes of work will be put more nearly on the same plane, as far as theoretical requirements and cost are concerned. It is of interest to determine what this will amount to on a 50-ft. deck plate-girder span weighing 14 tons and costing, reamed, $60 per ton erected. The number of rivets in the span will be taken as follows:

Flange angles to web	925
Flange angles to cover plates	925
Stiffeners and web splice	400
Bed plates	50
Lateral bracing	300
Total	2 600

At $3 per ton, the average price given by the author, reaming costs $42, about 1.6 cents per rivet. Any change in rivet values would affect appreciably only the number of rivets in the flange angles, and for the change in total shop cost caused by a rivet more or less may be taken the cost of material plus laying off and punching, and driving the rivet. At 5 cents per rivet, 840 additional rivets could be driven before the cost of reaming would be equalled, and in one-third the time it would take to ream, and it would thus not be economical to ream unless a

rivet in punched work was worth less than about three-fourths a rivet in reamed work. The area of a $\frac{7}{8}$-in. rivet upset to $\frac{31}{32}$ in., as in punched work, is increased over 20%, which excess is not considered in order to be on the side of safety. For a $\frac{7}{8}$-in. rivet upset to $\frac{15}{16}$-in. in a reamed hole, there is less reason for disregarding the increased area of 14.8 per cent. Increasing the unit strain in proportion will cause a saving of 240 rivets in the flanges, which, at 6.6 cents, amounts to $16, over one-third of the cost of reaming. This may be stated as follows: Mr. Rousseau.

	Cost.	Per cent.
Punched work	$798 00	100
Reamed work, with increased rivet value	824 00	103.3
Reamed work, with ordinary rivet value	840 00	105.3

What is wanted at present is to know how long reaming lengthens the life of a structure or decreases its cost of maintenance. A practical experiment of the matter could be made on any railroad bridge having a number of spans of equal length, some spans being reamed and others punched, and by comparing results. The opinion is ventured that in general if the cost of a structure were to be increased 5%, better results would be obtained by expending this amount on more material than for reaming. To those who are not in favor of reaming, the objection is not that reaming is not a good thing in itself, but that it is not worth, to the ordinary purchaser, in prolonging the life and increasing the efficiency of the structure, what he has to pay for it.

Horace E. Horton, M. Am. Soc. C. E.—As to metal, material, and workmanship for elevated railroads, the writer does not understand the requirements are essentially different than for bridge work in general. It is interesting to note the modification in the ultimate strength of metal specified and used over a term of years. Thirty years ago iron of over 60 000 lbs. tensile strength was demanded; however, iron of 48 000 lbs. tensile strength was the accepted standard when iron went out of use for structures. Steel first used in structures was of 150 000 lbs. tensile strength; later, 80 000 lbs. seemed to be the favorite, and now the author shows the exact percentage of advantage in the use of 64 000-lb. steel. What is to be the ultimate strength demanded for structural steel in the future can only be a matter of conjecture, but the writer thinks it reasonable to conclude that within a short period steel for structural work will be demanded of under 56 000 lbs. tensile strength. While in the past steel-makers have not been prepared to furnish steel of this character, and it now can only be had at increased expense, indications are that this extra cost will be modified or eliminated at an early day. Mr. Horton.

No one at this time will offer to use 150 000-lb. steel, and it is difficult to find an engineer who would justify himself in using three-quarters the bulk of 80 000-lb. he would of 60 000-lb. steel to accom-

Mr. Horton. plish a definite result. The author uses 7% less material of medium steel than he would of mild steel, and nearly offsets the estimated advantage by increased cost of manufacture. If his estimate is modified to fit the market as it is at this time, that is, manufactured structural material, f. o. b. Chicago at 2 cents instead of 3 cents per pound, as he indicates, his estimate of the cost of reaming would be from 5 to 10%, or an average of 7½%, somewhat in excess of the advantage named for extra strength.

The writer does not believe any such objection exists in the minds of manufacturers to reaming as indicated by the author. That they are not fully advised as to the exact cost is undoubtedly the fact. Whether it is $2 per ton, the minimum named, or $7, the maximum asked, has not been proved. Further, the manufacturer finds himself at a loss in tendering on work which demands reaming, to judge whether it is to be accomplished by mental science process or by physical act. While reaming has been specified for most steel bridge work for the past fifteen years, many of the manufacturing concerns of the country are in shape to do reaming only by the method which the author terms "humbug," while others are prepared to ream with drills from one-tenth to one-fifth the capacity of their rivet shops; hence, the conclusion is irresistible that a very large percentage of the reaming previously specified has been accomplished by an incantation pronounced over the punching machine.

The author proposes to ream rivet holes $\frac{3}{16}$ in., that is, $\frac{3}{32}$ in. on each side of the hole, as a remedy for misfits of $\frac{1}{32}$ in. named as common in punched work. Evidently he has been unfortunate in his acquaintance, and further seems to overlook the fact that a concern which has rivet holes misfit by 1-8 in. will do slovenly work even when reamed. The writer's observation leads him to conclude that the punching of rivet holes and the driving of rivets is not more careless than much criticism. He has never seen a rivet go loose in service where the design was rational and there was any reason to expect satisfactory results from the rivet, and further diligent inquiry among those whose observation has been the broadest verifies his experience as stated.

The reaming of rivet holes in metal work in the future must depend on the disposition of the proprietorship to pay for such reaming. The case where the ownership, as described in the paper, was ready to pay for reaming, in fact insisted on having it done, turns on the further fact that the ownership was advised by its engineer that less reamed material would furnish a more valuable structure at less aggregate cost. It would be more instructive if there was an example of where proprietorship had shown a readiness to pay for the extra cost of reaming, where the extra cost would be 7½% of the value of the manufactured material, and the advantage lie only in an improvement in the

feelings of the engineer. Examples of this character would at once remove all objection on the part of manufacturers to reaming, but when the argument is based on building a better structure with a smaller quantity of less reliable material, the writer believes proprietors, manufacturers and engineers all have reason to be sceptical, and he doubts if practice will follow the suggestion. Mr. Horton.

There are at this time three elevated roads operating in the city of Chicago, all of recent construction. Two of them have been reorganized, and the third is in the hands of a receiver. A fourth has considerable work of construction done, and the daily press states that it is negotiating for funds to carry the enterprise to completion. All have to meet the competition of well-equipped cable and electric street car lines as well as surface railroads, all of which competition would naturally point to the construction of elevated lines in shape to serve their patrons with the least discomfort, placing their cars as near the street grade as possible.

The author shows a structure with an elevation above street surface at the base of the rail of 21 ft., which is essentially the elevation of the roads built and projected, while the city requires a clearance of 14 ft. This makes it possible to use an elevation of 15 ft. to the base of the rail ; that is, the entire system of Chicago is built 6 ft. higher to the base of the rail than the requirements of the city call for, while three of the four lines projected and built are largely on private right of way. The extra expense of building through bridges for street and alley crossings would have been balanced by the decreased cost of construction of the other parts of the line, while such parts of the line as have been built in the street would have been either through construction or carried on single columns on the curb line, where girders could have been placed under the rails. This would require modification of ordinance, and be attended undoubtedly with some difficulty, but it would be not at all impossible. Further, curves and intersections in the streets would be attended with greater difficulty than by the present method of construction, as undoubtedly many cases would develop where the tracks would have to be suspended from overhead girders.

It is also apparent the floor of car might readily be 3 ft. from the base of the rail instead of 4 ft. Thus the elevated structure would fulfil the demands of the city for a clearance of 14 ft. and be only 18 ft. to the floor of the car, instead of 25 ft. How much of the financial distress, past, present and to come, the useless 7-ft. elevation has and is to cause is entirely a matter of speculation. It surely requires energy on the part of the patrons of the road to overcome it. It cannot be demonstrated that the elevated structures would have been a great financial success if 7 ft. lower. That they would have had a more nearly even chance is obvious.

Mr. Mogensen. O. E. Mogensen, Assoc. M. Am. Soc. C. E.—An elevated railroad presents in its general character and in its manner of construction more uniformity than most steel structures, as the single members and typical details once adopted are to appear over and over again throughout the work. Hence a thorough and detailed study, such as has been made by the author, is of great importance in order to obtain the strictest economy in construction, manufacture, and maintenance without sacrificing strength and rigidity in design. That the preliminary work had been successfully carried out by the author, and that every detail had been carefully considered when the contract was let, is shown by the fact that the last portion of the structure now erected, as well as the first, stands as a true copy of the typical drawings on which the contract price was based, and from which the cuts are reproduced.

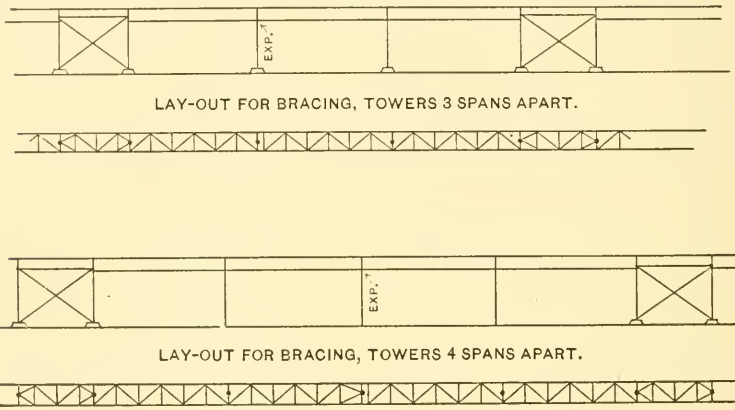


Fig. 32.

This is evident from the fact that only one alteration, even of minor importance, was made in the lateral bracing, which originally was designed as shown in Fig. 2.

From this general plan it will be seen that the longitudinal thrust from the girders is carried into the columns by a triangular bracing on both sides of each column. This was necessary in order to avoid the horizontal bending in the top and bottom flanges of the cross-girders due to temperature stresses. However, in detailing the cross-girders the section adopted for the flange angles was found to be sufficient to carry both the horizontal bending plus the strain due to the maximum live and dead load on the structure, for cross-girders spaced but one span length from the tower bents. The bracing was, therefore, changed as shown in Fig. 32, thereby simplifying the manufacture and the field work on the columns.

Mr. Mogensen.

It should be noted in this connection that the omission of the triangular bracing was made only in structures on tangents, whereas the structure on curves remained as shown in Fig. 2, with additional lower lateral bracing, as mentioned by the author in § XX.

In speaking of the riveting of work punched to full size, the author condemns the use of the movable air reamer used to enlarge eccentric rivet holes. In this connection the writer would state that it is a well-known fact among inspectors that less loose rivets are encountered in work punched to full size than in reamed or drilled work. This may be explained by the fact that the looseness of rivets driven through an irregular hole is much more difficult to detect than loose rivets driven through a perfect, cylindrical and smooth hole, as the crooked rivet naturally gives much greater friction to the irregular surface formed by the eccentric holes.

This is another good reason which speaks for the sub-punching and reaming or drilling in main members of structural work; whereas, punching to full size, when carefully done, will, in the writer's opinion, suffice for light work and for members of secondary importance.

The full value of sub-punching and reaming rivet holes in preference to punching to full size is somewhat impaired by the fact that the adjoining plates in long members may not come in tight contact with each other at the rivet holes. It is not seldom found that these voids are wide enough to allow the blade of a pocket-knife to pass between the plates close to the rivet. These voids are caused by the drilling. When the tool has passed through one plate and commences to pierce the other, the two plates spread enough to permit the steel shavings to locate between the plates around the rivet to a distance of 3 ins. from its center. The removal of such shavings is a very simple matter, which would hardly necessitate the loosening of the bolts, but which should be done in order to derive the full benefit of the reaming or drilling of rivet holes.

Among the various designs so thoroughly discussed by the author, a comparison between steel and wooden floor systems has not been taken into consideration. As the Northwestern Elevated Railroad, with the exception of a small portion of the line, occupies private property, it is hardly probable that any city restrictions would have excluded the use of a steel floor system, which for several reasons seems of advantage for a structure built so substantially and for which, without doubt, greater economy in maintenance and durability during operation have been considered of more importance than an imaginary saving in the first cost.

The extra cost of a corrugated floor above that of a wooden floor system of vulcanized timber is justified by the following advantages:

Mr. Mogensen. *First.*—When properly designed it will last as long as the main members in the structure.

Second.—As a lateral system it will increase the rigidity of the structure materially, and thus take the place of the upper lateral system, which is needed for the wooden floor system.

Third.—In case of fire from any of the adjacent buildings, destruction to the structure and interruption of the traffic might be avoided.

Fourth.—Cost of maintenance and inspection is considerably lower than that of a wooden floor system so heavily loaded.

Fifth.—Fifteen, thirty or forty-five years hence, yellow pine or equally good timber may not be had for the market price quoted to-day.

In using a corrugated floor the longitudinal girders may be raised far enough above the top flanges of the cross-girders to act as guard rails, which would necessitate a spacing of about 7 ft. 2 ins. center to center of the longitudinal girders.

The first cost of such a floor stands as about $11.10 per linear foot of structure to $6 28 per linear foot of structure for the wooden floor system, based on the price of $38 per 1 000 ft. B. M. for vulcanized timber in place, as quoted by the author. This would mean an extra cost of about 15% to be added to the total cost of the line, which is quoted as $32 65 per linear foot of line for Design 6.

If the life of the vulcanized timber be put at fifteen years, these figures show that in less than twenty-seven years the money expended for a wooden floor system would amount to the same as the entire cost of the steel floor, disregarding the greater cost for inspection and maintenance of the wooden floor system. It may be said that the steel floor directly supporting the rail would cause greater vibrations, noise and wear upon the structure than the wooden floor system. But has not the experience of recent years demonstrated the superiority of the steel floor system over the wooden floor system, which needs constant attention after a service of four to five years, which attention is especially dangerous on an electric elevated railroad, operated by the third-rail system?

Mr. Hall. Wm. M. Hall, M. Am. Soc. C. E.—The author's specification for fineness provides that 90% shall pass the No. 100 sieve. It is believed that most of the foreign Portlands will not pass this specification, although they are equal or superior to the best domestic makes. It would, therefore, be interesting to know if the foreign makes were excluded by this specification, or if the manufacturers shipped, or proposed shipping, cargoes of especially fine ground cement to meet the requirements. The specification for tensile strength appears to give a maximum as well as a minimum limit. The minimum in all cases is very low. Most specifications give only the minimum tensile strength, which, for briquettes treated as specified, is now usually placed between the figures following, viz.:

Pure cement ...	7-day	briquettes,	between	400	and	500	lbs.
"	28 "	"	"	475	"	600	"
1 cement, 3 sand.	7 "	"	"	120	"	180	"
1 " 3 " .	28 "	"	"	170	"	250	"

Mr. Hall.

It has been considered not detrimental to a cement to show a higher tensile strength for short-time tests than any of the maxima given in the author's specifications, unless it was shown to recede later in strength. It is, therefore, not clear to the writer why they are given.

In no part of these specifications is the temperature of air or water mentioned. The temperature of both, however, is an important factor in the time of setting, and also in all other tests. Therefore the writer believes that the temperature of water for mixing should be accurately specified, and the temperature of air in the testing room approximately so.

J. C. Ostrup, Assoc. M. Am. Soc. C. E.—In comparing the merits of the many excellent designs presented in the paper, the writer will confine himself to those of Design 1, Fig. 12, and to Design 10, Fig. 21. Some of the more important advantages in Design 1 are found in the fact that the short transverse girder for each track and its bracket and column are made in one piece in the shop, and that the web plate through these parts is practically continuous; its cheapness, costing about $11 200 less per mile; its greater rigidity and facility of manufacture and erection. For these reasons this design was adopted for the Northwestern Elevated Railroad, but over this design, Design 10 has, in the writer's opinion, one material advantage. It will be seen in Fig. 9 that the short transverse girder projects $3\frac{3}{8}$ ins., which, with the additional amount of projection caused by the rivet heads, is increased to about 4 ins., above the plane of the longitudinal girders. This feature is eliminated in Design 10, which would be a material advantage when placing the floor system or track work on the structure. Mr. Ostrup.

For various reasons, which are immaterial to this discussion, it is intended on all curves of the Northwestern Elevated Railroad and the Union Elevated Railroad to use beveled ties spaced 15 ins. center to center, and to place them radially to the curves. Local conditions have in most cases rendered it impossible to place the bents or transverse girders radially, and their direction is therefore at variance with that intended for the cross-ties. Consequently, it will be necessary to change the direction of all ties in proximity to the cross-girders, or to adze down the ties by 4 ins. where they cross the top flange of the transverse girders, both of which methods are undesirable. Even supposing that all the cross-girders could be located radially, the width of their top chord would, of necessity caused by local conditions, vary from 10 to 14 ins. As the ties are 8 ins. wide and

Mr. Ostrup. spaced 15 ins. center to center, this leaves a clear space of 7 ins. between two adjacent cross-ties. This space of 7 ins. would be anywhere from 10 to 14 ins. at every bent, and produce an irregularity which is also undesirable.

In regard to the merits of the braced towers, the author seems to have shown some unnecessary modesty in not describing their great and undisputed advantages more fully. On all elevated roads the expansion pockets are generally spaced about 150 ft. apart, with a clear opening in the pocket of from 2 to 4 ins., according to design and accuracy in the triangulation work, and, therefore, a structure of this kind forms a series of independent sections, each 150 ft. in length. The chief object in view, when designing every detail of an elevated railroad expected to pay interest on its invested capital, should be rapid transportation. With the utmost universal use of electric power for the competing surface cars, its financial life depends almost solely upon this point. Therefore, it is necessary to propel a train over this non-continuous structure at a rate of say 40 miles an hour, and to start and to stop the train as quickly as the traction will permit. All this causes a great amount of vibration. The idea of properly checking this vibration, which is greatly detrimental to the rigidity as well as to the life of the structure, seems to have been almost entirely overlooked heretofore, and is solved excellently and effectively in Design 1. Another highly commendable point in favor of this feature is the fact that these braced towers reduce to a considerable extent the total weight of metal in the structure, which reduction, according to the author, amounts to the surprising figure of 9 per cent.

Mr. Campbell. C. E. H. Campbell, M. Am. Soc. C. E.—In the author's study of the elevated railroad question, it seems that he has almost exhausted the points of discussion himself by presenting some fourteen different designs and arrangements of structures, with comments thereon. As to the specifications and designs necessary for the construction of such structures, when certain requirements are fixed and conditions determined and the structural engineer takes hold of the case, the results are generally dependent on his knowledge and experience, assisted by information that he is able to collect from others who may be skilled in that line. The author seems to have pursued this method, and reached out further by investigating defective features in existing structures, and such endeavors to remedy defects cannot fail to improve production, if the man who prescribes the remedy knows all about the disease.

The author dwells at some length on the matter of reaming. From the engineer's standpoint, where the nearest possible approach to perfection is desired, his deductions cannot be denied.

From the manufacturer's standpoint, objections will be in inverse proportion to his facilities for performing this class of work. The

writer's opinion is that if any built member, whether in tension or compression, has assigned to it a fixed value of working stress per square inch, this fixed value is based upon the physical properties of solid, perfect and faultless material, and the joining together of the component parts of the member by rivets, bolts, welds, or any other method, should be so perfect in detail that there will be no defect in the member against which it is possible to provide. Punching acts in the nature of a force applied almost instantaneously, with power enough to tear or shear a hole through the metal. The part that is thus disrupted is torn, bent, bruised and evidently damaged for at least a small distance around the hole, and it is evident that those parts that are thus distorted cannot have the same effective strength per unit as the original sound piece. Further, if part of the rivet holes match and others do not, there must be an unequal straining of the particles of metal in the member, even if the rivets fill the holes fairly well. The writer has heard some manufacturers claim that if reaming is deemed necessary, then each piece can as well be reamed separately before assembling. This is evidently wrong, as the chance for bad matching of holes remains the same as before reaming. To produce perfect results, all component parts should be assembled before reaming. The results obtained by the use of portable reamers are somewhat questionable, depending to some extent on the intelligence of the workman handling the machine. The use of stationary reamers places results beyond question. Mr. Campbell.

Regarding longitudinal bracing and the vibration incident to the lack of it, the writer had an opportunity to observe this defect in the Sioux City elevated road, some 6 000 ft. in length, in which there was no provision whatever made for traction force, and dependence was placed only on the riveted connections between the ends of girders and columns. The vibration was plainly noticeable at a point 2 000 ft. from the moving train. What effect this will have on the connecting rivets remains to be discovered.

The question of painting metal in such a way as to preserve it for any length of time from the action of the elements has been the subject of considerable talk, with but small results. The custom of oiling metal at shops or mills produces no good results, further than protection from rust during manufacture and transportation. Oil is a poor foundation on which to spread the paint. The protective element in paint is the pigment, and the oil the medium by which it is applied. Therefore, if anything is put on the metal at shops or mills, it should be the best protective compound known.

The author takes occasion to mention the frequent practice of some bidders of attempting to throw discredit on the plans and specifications of the consulting engineer. The writer ventured the opinion that he who knows all about the disease is qualified to prescribe the remedy.

Mr. Campbell. While the author has diagnosed the case in question, he has encountered another kind of disease. This malady often gets a grip on engineers and proprietors of some manufacturing concerns, and they determine that the consulting engineer does not know what his employers want, but that they do. Therefore they attempt to ignore the engineer's designs by submitting "much superior" ones of their own special make. Such designs are generally made to conform to their individual shop practice and the most economical shapes rolled by their own mill, and the only object in view is cheapening the product to the manufacturer, and obtaining contracts with more profit than if taken on the engineer's specifications.

Mr. Osborn. FRANK C. OSBORN, M. Am. Soc. C. E.—The writer takes pleasure in heartily indorsing the paper, as a whole, but would like to call attention to a few points mentioned by the author, with the idea of emphasizing them. The first of these is the requirement in regard to providing "adequate means of transmitting the thrust of braked trains from longitudinal girders to columns without overstraining the cross-girders," and the proportioning of columns to "provide sufficient strength to resist direct load, bending from longitudinal thrust, bending from transverse thrust, and on curves bending from centrifugal loads." These features of design have frequently been lost sight of entirely, and their importance ought to be recognized fully, for the reason that the stresses requiring these provisions occur at every passage of a train. It should be borne in mind that any stress applied to such structures must eventually reach the earth, and proper provision ought, of course, to be made for its doing so.

In regard to the importance of good design, material and workmanship for elevated railroads, it seems that these requirements are, if anything, even more important than for ordinary steam railroad bridges, for the reason that trains are much more frequent, and they are being constantly stopped and started at stations which are comparatively short distances apart, making the punishment to which an elevated railway is subjected much more severe than that of an ordinary railway bridge.

The writer agrees with the author in the preference for medium steel with sub-punching and reaming over soft steel without the reaming. A gain is effected on account of the greater strength of the medium steel, and the reaming is certainly advisable, as it removes the injured metal in the immediate vicinity of the hole and makes a better job from a workmanship standpoint. Objections to reaming and drilling appear to come principally from manufacturers operating small plants without facilities for doing this kind of work. Some manufacturers, however, although fully equipped to do the work, are in the habit of bidding on work for which reaming is specified and then doing their utmost to have the reaming waived, solely with the

view of increasing their profit. The practice of a number of manufacturers of always endeavoring to have modifications and changes made in plans and specifications and solely with the idea of diminishing the cost of the work to themselves, without any advantages whatever to the purchaser, is one hardly to be recommended. This policy, in a number of cases known to the writer, has led to the placing of the contractor at a positive disadvantage on subsequent work. Mr. Osborn.

In regard to faulty details, that of connecting members together by riveted joints without paying due attention to the proper intersection of gravity lines is probably as common as any. The only excuse for it ordinarily is the saving of a very small amount of material in the gusset plates.

The writer fully agrees with the author regarding the attachment of cross-girders to columns. This connection should be as rigid as practicable, and this can best be accomplished by running the column up to the top of the cross-girder and riveting the two together thoroughly.

It is the opinion of the writer that what is known as carbon primer is superior to linseed oil for a first coat for structural iron or steel. It is thin, flows readily, and unites firmly to the metal. It dries hard and does not give the greasy surface to metal that linseed oil does. It makes a finish to the metal surface that permits the laying out of work as readily as upon the raw material. The carbon primer should be applied as soon as practicable after rolling, and certainly before any tendency to rust appears.

As to the æsthetics of structural steel designing, it is certainly time that engineers gave serious attention to this point. For the ordinary railway structure, architectural appearance is not particularly important, as but few people have occasion to view it. For city or suburban bridges, however, and particularly for elevated railways, the question of appearance is a live one and well worth careful study and consideration by engineers. An engineer as well as an architect owes it to the general public to give a structure satisfactory not only from a utilitarian standpoint, but from an artistic standpoint also. This artistic effect is not necessarily obtained by elaborate ornamentation, in fact too much or inappropriate ornamentation may be worse than none at all. The desired effect may frequently be obtained by a proper and careful study of the principal lines and form of the main structure. A structure may have little or nothing of pure ornamentation and yet be very pleasing to the eye on account of its natural grace and apparent adaptability to the purpose for which designed. Engineers, as a rule, give too little attention to the architectural effect of their structures, and they will doubtless concede that the author has made a distinct and satisfactory advance over what has heretofore been done in this direction by American engineers.

Mr. Pratt. WM. ARTHUR PRATT, M. Am. Soc. C. E.—The writer has had experience only with elevated viaducts designed for the heavy loads of ordinary steam roads. The conditions are different in the case of rapid transit lines in city streets, whether the motive power be electricity or steam, but the traffic is no less constant than in case of the heavier structures. To one who has had to do with the construction and maintenance of these viaducts, several facts are very apparent:

First.—The service is extremely severe, especially on those viaducts forming approaches to important trunk line terminals.

Second.—The deterioration of the structure is much more rapid than in the case of equally well designed work of other types on other parts of the line.

Third.—The foundations require most careful treatment in design and construction, and frequently show settlement, and require more or less extensive repairs before the superstructure develops any weakness.

The writer therefore holds that minimum first cost is not necessarily synonymous with true economy, and that the use of medium steel with high unit stresses, thereby reducing weight and increasing deflections, is a move in the wrong direction. The writer believes from a careful observation of the behavior of many viaducts in actual service that the most durable and satisfactory are those very heavy structures with solid through floors and stone-ballasted roadways. While this latter style of construction is probably not available for a rapid-transit elevated railway built in the streets of a city, the engineer can at least use comparatively low unit stresses, thereby reducing deflections to a minimum and providing additional mass to absorb the impact of the moving load. If low unit stresses are used, there remains no imperative reason for using medium steel, as the ultimate strength and elastic limit of the material are no longer in question; and if soft steel is used, the writer sees no reason for a general reaming specification as his experience shows conclusively that there are several bridge shops in the country which can turn out punched work with an accuracy leaving but little room for criticism.

The author's figures are very seductive, but the writer is by no means convinced thereby that the four-column bent is the best arrangement for a four-track viaduct. The reason for this lack of faith is in what has been previously said about the uncertainty of foundations under viaduct columns. As a case in point the following testimony is submitted. The facts pertain to a viaduct for which the writer provided the superstructure.

Foundation beds, good, compact gravel. Lower course of masonry, concrete 11 ft. square, 3 ft. thick. Balance of foundation, heavy, undressed ashlar in regular courses. Caps, sandstone, 42 ins. square, 20 ins. thick, four anchor bolts in each foundation. Maximum load, 250

tons, of which about 140 tons is live load. Pressure on foundation beds, about 2 tons per square foot. Mr. Pratt.

About 100 of these foundations were built, all of substantially the same character, the beds being apparently of the same good material throughout. After five years' service, 60% of these foundations showed settlements varying from 1 to 3 ins., and of the remainder almost all showed an appreciable settlement.

Additional testimony could be furnished if necessary, but the tenor of it would not differ from the preceding. The writer therefore believes that having determined upon a satisfactory span-length, it is good practice to reduce the number of column foundations to a minimum, using not more than two in a bent, unless other conditions require a modification of this arrangement. This reduces to a minimum the number of points liable to settlement, and the consequent distortion of the structure becomes a less serious question. The liability to settlement of foundations leads the writer to believe also that wherever physical conditions will permit, it is better practice to design the structure with the longitudinal girders carried on the upper flanges of the cross-girders, rather than riveted to the webs of the latter. In case of unequal settlement of adjacent bents, the latter detail would involve severe and possibly destructive strains in the header connections; while but small harm would be done if the track girders were simply seated on top of the cross-girders.

The author believes that a shop coat of boiled linseed oil on finished members is all that is required before erection, and this is also the present practice of the Pennsylvania Railroad Company. Some recent developments in connection with the bridge work of this company have led the writer to believe that this practice is not good. An order of plate girders with $\frac{7}{8}$-in. rivets passed the shop inspection before the oil coat was applied, and the riveting was fully up to the high standard of the shop which furnished the girders. After the delivery of the work and during the erection, the railroad company's men discovered that far too large a percentage of the rivets were loose, and this led to a careful investigation with experimental pieces which were riveted up and tested for loose rivets before and after oiling. The fact was developed that rivets which were tight before oiling could in most cases be readily loosened with an inspector's hammer after the oil had penetrated around the shank of the rivet. The effect of the oil was to soften the scale on the surface of the rivet, at the same time reducing the friction of the rivet heads like any other lubricant. The test pieces were then cut through the center lines of the rivets and showed that the upsetting had been practically perfect. The experiments therefore seemed to show that while many of the rivets would have been condemned by an inspection after the oil was applied, the situation could not have been improved by cutting out and replacing these

Mr. Pratt. rivets. In the writer's judgment the above facts are a possible explanation of the comparatively large number of loose rivets which occasionally appear in certain girder spans that give no indication of poor work during the shop inspection. If the girders were placed in service while the oil was still fresh, they were subjected to substantially the same conditions as were the experimental pieces which were tested after oiling. In the writer's opinion it is better to give the finished pieces a heavy priming coat of some approved paint in the shop than to use linseed oil alone.

Mr. Boller. A. P. Boller, M. Am. Soc. C. E.—In discussing a paper like the author's elaborate examination of the problems involved in the construction of elevated railroads, it is impossible within reasonable limits to comment on all the points he takes up. In his sweeping condemnation of all past efforts in this direction, he seems to have forgotten all modern work is a development of the past, and his own excellent work would not have been possible except for the labors of those before him. In the early days of such roads, the science of constructive engineering was only taking shape in this country. The problems involved, as they are now seen, are not complicated, unless one chooses to make them so. The construction is simply a continuous line of girders supported on columns resting on pedestals arranged, as to span and support, according to the local requirements of any given case, and an economical balancing of spans and supports as near as it is practicable to do so, subordinate to the necessities of street traffic. The constructive details necessitated thereby are a matter of the individual taste of the designer, so long as they are controlled by principles of statics and the laws of the strength of materials used, coupled with a full knowledge of shop methods and facilities.

Such structures are not subject to any architectural treatment whatever, and should be built as unobtrusively as possible. The writer prefers plate girder work to lattice work, as it can be made shallower, even at the expense of a little more flange material. For straight-away work, he has always thought the type of the Third Avenue line in New York City, of course detailed with modern ideas, was about the best for a wide avenue, where posts could be put in the avenue, being the least obtrusive. For a narrow street, or where otherwise required, of course there is nothing left but to put columns inside the curb line and girder across the street.

As to pedestals he believes monoliths of well-made concrete are the best, and that the specifications for cement in the paper are eminently sensible, and calculated to produce good results. He is prejudiced possibly in favoring natural stone for cap stones, although the author seems to have obtained satisfactory results with artificial granolithic stone. The author lays great stress on his manner of bolting his

column to the pedestal, but in an ordinary standard pedestal, there is the weight of a comparatively small volume of material above the anchor washers, and were there anywhere near the strain on the bolts he imagines, it would have told long since on some of the pedestals of the New York and Brooklyn roads. This idea of pull on the bolts he has derived from an assumption that 20% of the live load between two adjacent expansion points acts as a horizontal thrust. So far as the writer knows there are no exact data on this subject, but he does not believe it is anywhere near that figure. The rails, guards, etc., are continuous, and distribute what thrust there is over a long distance. The author would ignore this part of the structure as a distributing factor, and go to much trouble and expense to make the structure entirely independent of it. The rails and guards exist, and will do their distributing work, whatever it is, and why ignore them? Many years ago, when the original Greenwich Street line in New York was running, this question came up, and the late Milton Courtwright, M. Am. Soc. C. E., made some experiments as to the effect of braking trains on this, the flimsiest, structure ever built for elevated railway purposes. The writer does not know that these experiments were ever recorded, and doubts if they were made with any scientific refinement, but he remembers Mr. Courtwright telling him that whatever horizontal thrust the brakes produced was so small that it was a matter of no moment, and demanded no special provision. Mr. Boller.

Growing out of this fear of horizonal thrust, the author has evolved a column of heavy cross-section necessitating some complication of detail. His column is a good one, of course, but from magnified assumptions of stress, he has magnified his column beyond necessary requirements. The writer likes his idea of running the columns past the ends of the cross-girders, instead of simply resting the girders on top of the columns, when posts are on sidewalks, also throwing in a strut between longitudinal girders and column head, as well as solid plate-girder corner brackets. These add much to general stiffness, and such structures cannot be too stiff.

The author calls attention to rust conditions around the foot of planted columns, but just how this is to be avoided it is difficult to see. To carry up the capstone above the street surface sufficiently to remove the column above moisture is impracticable in most cases, on account of creating too much obstruction in the streets. His idea of filling the boxed space around the column foot with concrete amounts to little as a protection, as no concrete ever made is impervious to moisture, and it is impracticable to get intimate contact between concrete so placed and the detail of the metalwork. Presumably the only thing that can be done is, before concreting, to plaster the metal surface thoroughly with cement mortar, but even such mor-

Mr. Boller. tar is only less permeable to moisture than the concrete. This matter is a serious one for all such constructions, and the writer knows of no way of getting rid of the difficulty. The nearest approach to protection is the column planted in a cast-iron pocket, the neck of the casting rising some inches above the plane of the roadway or sidewalk, the voids between columns and casting being well grouted with cement. The greater part of the New York elevated construction is of this character, but coupled with this form of construction is the difficulty or impossibility of getting solid contact between the post-end and the bottom of the cast socket, which cannot be faced. The writer would suggest in any case a thorough priming of the post foot with the best attainable primer, which will not corrode under moisture, and then asphalting with a good natural asphalt. In the darkness and under moisture the volatile oils in such asphalt will probably hold for an indefinite time. Asphalted rails in the tunnel of the Fourth Avenue improvement have lasted well; the same asphalt exposed to sunshine soon becomes powdery and useless.

As to the use of medium steel or soft steel, the writer is an advocate of the former as being perfectly reliable, of higher value and strainable to a higher unit. There is a tendency toward the use of soft steel, encouraged and promoted by the manufacturers, as the supply is abundant, and ease of manipulation in the shop makes it cheaper to work. The engineer is impressed with the arguments of the manufacturer that he is using a safer steel, and one that will better withstand shock. This is all from mercantile interest, for can any steel be subject to higher shocks than rails, connecting rods, driving wheels, etc., all of steel of very much higher carbon than any contemplated for constructive purposes, the very hardness of which gives it value against deformations. Steel must be treated and manipulated according to its quality and grade, and the nearer it approaches homogeneous iron, which so-called soft steel really is, the less expensive is it to work, and the more desirable for the shop.

The author is quite right in all he says about reaming. All first-class riveted work should be reamed, if only for the purpose of truly matching holes, and perfect work can be attained only by reaming through all the parts assembled together. The use of a tapered and flexible reamer should not be allowed, except in some out-of-the-way place that a rigid drill cannot reach, but no prime joint or important connection should be designed so that the rivet holes are inaccessible. A concession for punched holes in soft steel might be made for gussets and secondary connections, but all direct connections, such as webs and flanges, should be reamed in any sort of steel adopted. Metal below $\frac{5}{8}$ to $\frac{3}{4}$ in. in thickness may be sub-punched and reamed; above that thickness, it should be drilled from the solid.

As to the choice between basic and acid steel, in these days there is

not enough difference between them to warrant a preference, except perhaps for eye-bars, where acid steel is the best, for the reason that the annealing of such bars causes such a drop in tensile strength from that shown by the initial steel, that as high a limit of ultimate strength steel should be used as is consistent with toughness and ductility. For this purpose acid steel, made as it is from the best quality of original stock, is the safest and best to use. Mr. Boller.

The author lays none too great stress on painting, but it does seem almost impossible to have this well done, particularly the vital priming in the shops. The writer does not think much, if anything, would be gained by oiling material in the rolling mill, as the author suggests, for there is much mill scale to come off during shop handling and manipulation, and such oil as remained would interfere with the primer getting in immediate contact with the metal. The best attainable primer should be employed, and it should be properly put on under cover, and dry before shipment. Most work is painted outside with extreme carelessness and shipped fresh, and between the cutting of cinders from the locomotives and the rubbing of pieces against each other, it reaches its destination in a condition no properly primed material should. As good priming is the essence of protecting metal against rust, engineers should exercise more care in the material they use, and see that it is properly put on under proper conditions. If economy is the order of the day, let it be exercised on the outer coatings. Manufacturers are not wholly to blame for sloppy shop painting, as time for completion of work is usually set at such a date that the strain to meet time expectations is intense, to meet which work must be shipped almost as soon as the last rivet is driven, and the shop priming is done on a sort of catch-as-catch-can principle. No work ought to be crowded quicker than it can be done rightly, and engineers, in so far as they can control, should see to it that the time exacted can be properly met.

The author's account of his letting, at which certain manufacturers tendered on other conditions than those asked for by the specifications gives an exhibition of practices entirely too common. In public works, the law compels the throwing out of such tenders as irregular, and it ought to be done in private lettings. It is eminently unfair to other bidders, and derogatory to the right relation between the engineer and contractor. It is highly impertinent in a manufacturer, when asked to tender under a certain specification, to ignore the requirements of the same, by bidding on a basis that better suits his own shop facilities, hoping to go over the engineer's head by attracting the buyer with a lower price. No self-respecting engineer should permit such an effort to succeed, and it is refreshing to see that the author stamped it out in his case. In making these remarks the writer does not wish to be understood as belittling the knowledge and

Mr. Boller. experiences of the shops, for much of the marvelous advance in constructive engineering is due to them, fully as much, if not more, than has been contributed by the purely professional brethren. But the wise engineer will familiarize himself with shop facilities and experiences in details and methods of construction, which every shop accumulates in the course of a business career in contact with many minds, out of which he will edit, as it were, the best practice for his own particular work. The writer has not much respect for the engineer who tries to evolve everything from his own inner consciousness, oblivious of the many bright minds that have added to the wealth of experience and possibilities. The author has shown great familiarity with the best shop practices and modern ideas of designing, and he has gleaned well from past experience with an enviable industry that became crystallized in such an elevated railroad as he wanted to build. In the face of this, to have a contractor asked to bid upon that construction of road come forward and turn the engineer's plans down, endeavoring to substitute some of his own, for purely commercial reasons, advanced under cover of more or less technical speciousness, was a very high-handed proceeding. It is certainly a satisfaction to know that the parties fell into the pit which they dug for others. In this connection the writer wishes to remark that after a work is awarded, it is perfectly proper to favor the successful shop by such modification of details as may best suit the special facilities and conveniences of that shop, without sacrificing any general principles. An arbitrary adherence to a notion is not good business or sensible engineering.

The author concludes his paper with some remarks on the æsthetics of designing, with an architecturally treated road as he would like to build one. It is sincerely hoped he will not have the opportunity, for if the elementary principle of sound architecture "not to construct decoration but decorate construction" can be violated, it has been certainly accomplished in the design submitted. There is a homely old expression, that "you cannot make a silk purse out of a sow's ear," which fits here, for you cannot make an architectural (æsthetic) structure out of an elevated railroad, despite false arches, foliated column caps, or gargoyles on the ends of the brackets.

Mr. Stuart. A. A. Stuart, M. Am. Soc. C. E.—While the writer desires to go on record as approving most of the conclusions reached by the author in evolving the various details of construction described in the paper, yet there are some statements made and details employed which he feels are neither founded upon facts nor sustained by experience. The initial statement that methods heretofore employed in designing structures for elevated railways are radically wrong is rather too sweeping to be sustained by facts, nor is it justified by a careful examination of the designs presented by the author, since they do not differ

Mr. Stuart.

in essential elements from recent designs employed in other cities where the limiting conditions were at all similar. There are differences in some of the details, but the relative merits of these are the subject for debate rather than the hasty judgment that any one is superior to all others. Such differences doubtless will always exist, and can well do so without subjecting any particular one to the charge of being radically wrong. The structure in Chicago chiefly treated by the author, being located on property owned or controlled by the railway company, made it possible to employ the braced-tower construction, which has never been applicable to the structures in either New York or Brooklyn, because they are located wholly in public streets. This feature constitutes the only radical difference between the author's design and the design of the structures built in New York or Brooklyn within the past few years, but its absence in the latter certainly does not warrant the statement or belief that their design is radically wrong.

As to the desirability of having all rivet holes precisely concentric in members to be united, there can be no question raised, but the writer's observation does not lead to the belief that the expense which would be entailed in securing this by the method suggested by the author would be justified. The use of riveted work in this country has been very extensive and covers a long period, but so far as the writer has been enabled to learn, the present methods of manufacture employed by the best shops have given satisfactory results under a large variation in service; hence any change in those methods involving so much additional expense does not appear to be warranted.

In the matter of Portland cement, the author's specifications are gravely inconsistent in that he exacts the best possible quality obtainable, while in the next paragraph a physical requirement is stated which the poorest cement in the market would fully satisfy. Indeed the wide latitude permitted in the tensile strength is of itself generally regarded as unfailing evidence of poor quality. The writer makes special reference to this here in the hope that it may at least serve in a small degree to eliminate such inconsistencies or ambiguous expressions from specifications, believing that they are the most fruitful source of contentions and disputes between engineer and contractor.

As to the track system presented by the author, it is almost identical with that used on the older roads in New York and Brooklyn, which has been much modified as a result of long experience on those roads. The writer has never been able to conceive of any adequate reason for using inner guard rails on straight track, but, on the other hand, will state what he believes to be several rational ones for omitting them. While it is possible for a derailment to occur on an unobstructed piece of straight elevated railway track, it is a very remote

Mr. Stuart. possibility when gauged by the fact that an experience of twenty-five years on the New York elevated railways furnishes no instance of such an occurrence. This fact alone would seem to deny the utility of these guards in averting calamity, the only purpose for which they are employed. Should a derailment occur, the question arises whether the outer guard rail does not offer ample security, if left to act alone, in preventing a truck from leaving the structure.

This is certainly true if the four guard rails are spaced, as in the author's design, so as to require each to act independently instead of in pairs. If inner guards are used at all, they should be so spaced that opposite wheels of a derailed truck would encounter an inner guard and the opposite outer one at the same instant, and neither guard should be laid so near the track rail as to prevent a derailed wheel from dropping into the space, except, of course, on curves. If the inner guards are never called upon to perform any service, then their use is not justified, and they should be omitted for the reason that they add additional perishable material to be removed, and otherwise increase the cost of track maintenance by shutting out air and sunlight from the ties, thus hastening their decay, and they add much difficulty in making repairs to track rails and ties. It is a matter of much surprise to see the use of short hook bolts revived by the author, in view of the evident advantages possessed by the long hook bolt, which engages the flange of girder, tie and outer guard rail in one mechanical operation.

Referring to the use of treated timber in the track system, the author's conclusions, not being based upon facts developed by experience, are very misleading. It is not true that yellow pine or any other timber used for structural purposes becomes unfit for further service after $7\frac{1}{2}$ years' use in elevated railway tracks, or even in surface tracks. A very large percentage of the timber laid in elevated railway tracks 12 or 15 years ago is still in service, and will so remain a number of years. The writer believes it to be a safe assertion that its average life is quite 15 years in such a situation, if not destroyed by mechanical means, assuming that reasonable care and judgment are employed in its selection. The largest number of renewals made within the first 10 or 12 years are rendered necessary by mechanical agents and not chemical ones. While it is true that the cost of labor for renewing a single tie averages about $1, it is not a fact that the largest percentage of timber would be renewed in this way, but in continuous sections, where the circumstances would reduce the cost of labor to a sum not much in excess of that required for laying new track. These facts would materially alter the author's conclusions if incorporated in his computations to ascertain the relative merits of treated and untreated timber.

From a theoretical standpoint, the author's criticism of the neglect

to proportion all columns for resisting flexure is fully justified, but the writer has satisfied himself by careful observation that the assumptions usually made as to the magnitude of stresses which the columns will be called upon to resist are very much in error, else few or none of the structures in New York or Brooklyn would be standing at the present time. These structures themselves afford the best and most reliable evidence of their ability to resist safely both longitudinal and transverse stresses which are brought into the columns, and a careful observation of their behavior under conditions producing maximum stresses will fail to disclose any evidence whatever that they are excessively strained. The writer has seen and very carefully noted the conditions where the transverse girders were cut entirely loose from the columns over a distance of nearly a quarter of a mile, the structure being supported temporarily on 15-in. square timbers clamped to the remaining stubs of the iron columns, and while in this condition a three-minute interval train service was maintained over the structure, which is on a 2% grade, without producing any increased vibrations so far as could be detected.* It seems to the writer that, in addition to other interesting features involved in this work, it furnishes confirmatory evidence of a very pronounced character that the customary assumptions relative to lateral stresses in such structures are not substantiated by facts, and it is believed that much metal has been wasted in providing for stresses which appear to exist only in the imagination. Mr. Stuart.

The cement finish used by the author to cap the concrete foundations has given very satisfactory results on Brooklyn roads during the past four years, but the writer does not believe that a mixture of one part cement to three parts of crushed granite, as described by the author, will give satisfaction, either in the matter of finish or durability, since it is too porous to admit of good troweling and prevent disintegration by frost. Indeed, this mixture is no richer in cement than the concrete used in the body of the work below the frost line, where it is protected from abrasion and the unit pressure is very much less than immediately under the columns.

ALBERT A. TROCON, M. Am. Soc. C. E.—The author says that "there is no bridge shop in existence which can turn out truly first-class work without sub-punching and reaming or drilling." The writer thinks there are a great many shops that can do so, or rather that all of them worthy of the name can, if the proper care is taken. The care required to do this is much less trouble than that caused by having to sub-punch and ream. The writer knows that in the shop with which he is connected, the punching is usually done so accurately that very little or practically no drifting is required. When the holes did not match, it was generally found to be the fault of the laying off, Mr. Trocon.

* See *Transactions*, Vol. xxxii, p. 363.

Mr. Trocon. and in these cases reaming would have been of no avail, as the holes were too far apart to be remedied in that manner.

The idea that rivets cannot be driven so as to fill the holes completely when the latter are punched only, and they are left of slightly varying diameters, seems to the writer erroneous, especially where the rivets are machine driven, which is the universal method in bridge and structural work, except in the few places where they cannot be reached by a riveter. He has quite often seen specimens of riveted work, with holes punched only and not reamed, sawed through the center of the rivets, where they so completely filled the holes that it was difficult to distinguish the lines separating the rivets from the balance of the material. Some of these specimens contained five or six plates riveted together. The writer thinks that most manufacturers will concur in his views. If it is the case, then, that holes can be made to match so perfectly by punching without reaming that there will be no trouble in making the rivets enter into their places, what is the use of requiring manufacturers to sub-punch and ream (when punching alone does not injure the material), thereby causing an extra expense of from 0.1 to 0.25 cent per pound? The writer thinks it good practice to ream holes for field connections, as this facilitates erection, but not otherwise, unless in steel so hard that there is danger of cracking the material in punching. He is not so sure, however, that this is required, even for medium steel, and certainly not for soft steel. The fact that most manufacturers do not like to ream work, as acknowledged by the author, goes to show that they do not think it necessary, and that they can do good work without it, as they otherwise would certainly rather ream their work and get paid extra for it than punch it unevenly and have to drift excessively, which would cost them almost as much as reaming, and for which they would not be paid.

Another point the writer does not believe in is that "every column ought to be anchored so firmly to the pedestal that failure by overturning or rupture would not occur in the neighborhood of the foot, if the bent were tested to destruction." He does not believe in it because it is impossible to accomplish it without a great deal of extra expense, and in some cases it is impossible any way. All columns should be well anchored, so well as to resist all shear coming against their bottoms and to resist tension if there is any. He thinks it preferable to treat the column as free at the bottom and increase the section in figuring for bending effects of longitudinal and transverse thrusts than to treat it as fixed and attempt to build it as such. It is doubtful whether the cost would be any more that way, in most cases, than with the anchors proposed in the paper, and the column cannot really be made continuous except by running it down and imbedding it in the concrete for a considerable distance, which would be very expensive and in many cases an impossibility. Again, there are cases where

the columns have no bending to take care of, when it would manifestly be a waste of money to anchor them so as to make them continuous. Mr. Trocon.

WM. BARCLAY PARSONS, M. Am. Soc. C. E.—An elevated railroad, if built along a street, should be designed primarily from the point of view of the users of the street and not from the point of view of the railroad. A street is not a proper place for fast-running, power-driven railways. Such railways can be better built for their own uses on right of way to be acquired for the purpose, and when so built can be more satisfactorily operated. If for any reasons it is necessary to use a street, and the abutting owners and the users of the street surface are made to suffer *pro bono publico*, the greatest consideration in the design should be shown for their convenience. Mr. Parsons.

A design for an elevated railroad, apart from meeting the requirements of a bridge structure, as laid down by the author in his points *F* to *O*, under the head of designing, should conform to the following general requirements :

First.—It should occupy as little of the street as possible.

Second.—Its columns should be placed so as not to interfere with vehicular traffic.

Third.—It should give the minimum obstruction to the passage of light.

Fourth.—It should be noiseless, or as near as it can be, to the passage of trains.

Fifth.—The tracks should be placed preferably over the center of the street and not over the sidewalks, so that the drip in wet weather will fall upon the tops of vehicles rather than upon pedestrians.

Sixth.—The structure should be inoffensive to the eye.

Strict economy in the design should be the last point to be considered, and therefore the spacing of the girders, both longitudinally and laterally, should be made to conform to local requirements. In order not to interfere with street travel, longitudinal and cross bracing between the columns, except at a clear height of 12 ft. above the surface of the street, is not possible. The ordinary heights, such as are to be found in elevated railroads, preclude any such bracing, and therefore, the only stiffening that can be given either longitudinally or laterally is by means of corner brackets. The author points out very carefully the necessity for both longitudinal and lateral stiffness, and states that all elevated railroads as at present designed are merely examples of what not to do. Had he gone into a criticism of these awful examples, he would probably have mentioned their lack of stiffness as one of their chief defects.

The writer some years ago had occasion to investigate personally the movement of New York elevated railroads under passing trains, which he did by means of a transit. He was surprised to find that on

Mr. Parsons. curves there was no movement perceptible beyond vibrations. This, however, was not the case with respect to longitudinal movement. At points near stations when the approaching trains applied brakes, the whole structure would move forward perceptibly. The instant that the brakes were released, although the train might still be in motion, the structure would go back beyond its original position and then move forward beyond the vertical hair of the transit, and back again before coming to rest.

Of the various designs submitted by the author for two-track structures, the writer prefers No. 8, where the outer stringers are in line with the columns. The objection urged by the author to this design

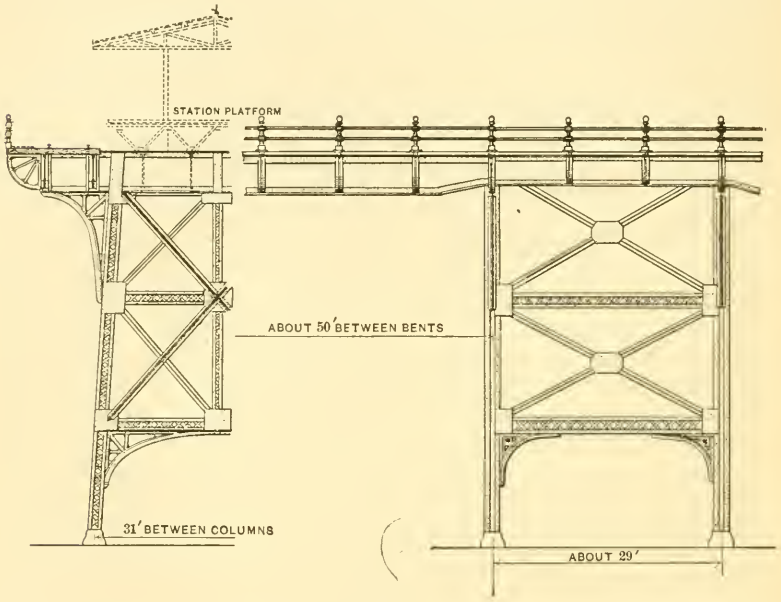


FIG. 33.

in regard to the bending of the cross-girders appears to the writer to be slight. Unless a column can be placed directly beneath the track, with stringers balanced about it, one stringer or the other will periodically be depressed slightly more than its mate. There is the advantage, however, of making at least one good connection, and of being able to introduce longitudinal brackets, which, like portal braces, can take up strain or movement.

The plans which the writer has prepared for the Rapid Transit Commission of New York include two designs for elevated railroads, one a high one across what is known as Manhattan valley, 2 800 ft. in length, and the other an ordinary structure. These designs are shown

in Figs. 33 and 34. In the high one provision is to be made for four tracks eventually, but only the two outer ones to be constructed immediately. The intertrack space is to be utilized for island platforms. On account of the height, 55 ft., the structure in side elevation has been divided into alternating long and short spans with the towers rigidly braced. The design for the lower structure follows the general lines of the author's Design 8, lateral and longitudinal stiffness being supplied by the curved brackets. Mr. Parsons.

The author speaks of making elevated railroads pleasing to the sight. That is an exceedingly difficult matter, if not impossible, unless the straight lines of utilitarianism aided by the details of good

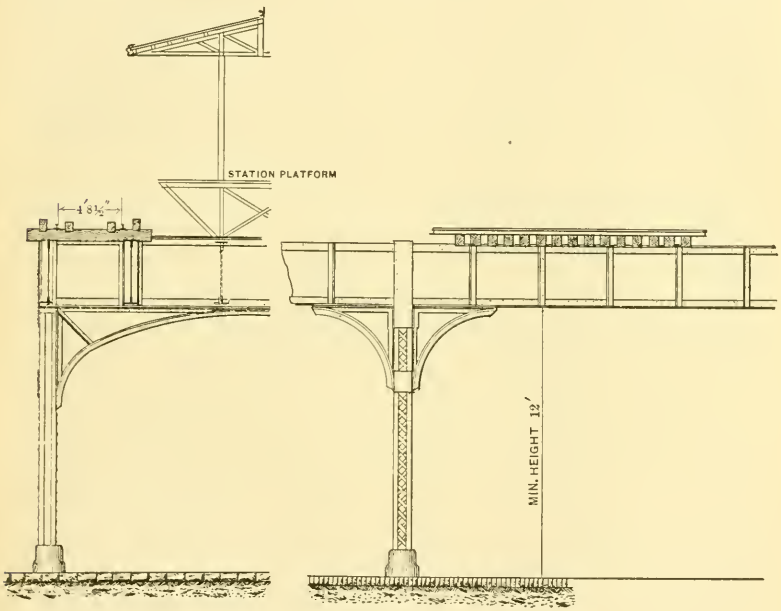


Fig. 34.

workmanship, can add beauty. Any built-up ornamentation, as in the æsthetic designs submitted by the author, will tend to still more darken and injure the street, and therefore by doing harm cannot be beautiful. It is to be remembered that true ornamentation should conform to, or suggest, the purpose of the whole, and the designs proposed by the author, while furnishing perhaps a pretty passageway to a ball room, do not in their details, especially in the loose and festooned hand rail, seem to the writer as in keeping with a railway. The author has, however, done a good thing in calling attention to the needless ugliness of most of our structures. That possibly the simp-

Mr. Parsons. lest details are the best is exemplified in the Stadtbahn in Berlin, where the Germans, although lavishly ornate in most of the design, were much restrained in treating the metal elevated way. The columns are small, so as not to take up space, and of cast or wrought iron. In either case the decorations are in keeping with the metal. The supporting stringers are usually a plate girder construction, and paneled between the stiffeners. The details of construction show care in execution and design. The side walls are bracketed out and so cast a deep shadow. The whole is pleasing to the eye.

Mr. Greiner. J. E. GREINER, M. Am. Soc. C. E.—The design of an engineering structure necessarily admits of a variety of means to accomplish the purpose intended, and the personal selection of any particular means does not imply that the preference is positively the best, or that a modification or different arrangement proposed by some other individual could not be equally as good. Therefore, while the author has pointed out what he considers the best cement, paint, span-lengths, dimensions of track rails, arrangement of wooden floor, material for pedestal caps, style of anchors, sections for columns, style of expansion joints, etc., the selections made are to be understood as only the best which his judgment dictates, and not as yet definitely settled by either common concurrence or the ballot box. As this is a matter of individual judgment and opinion, a discussion would be useless; but the writer would really like to know why one coat of linseed oil, one coat of Eureka paint, and one coat of oxide paint, all on the same structure, are considered the best metal paints to adopt. There must be some reason for this variety.

The question raised concerning the use of the basic process for steel of a medium grade is an important one, as it is the tendency of the mills throughout the country, at the present time, to make just as little acid open-hearth steel as they possibly can. Basic open-hearth metal, when over 60 000 or 61 000 lbs. ultimate, is not so uniform in quality and probably not so trustworthy as the acid steel, which must be made from a superior grade of ore, and the mills would always prefer to furnish the basic, which can be charged with cheap ores.

There is also a tendency at the present time among the different bridge shops, even those of the highest standing, to under-rate the value of reaming and drilling a medium grade of steel. Of course all can understand that the object of the bridge shop is to manufacture a bridge just as cheaply as it can be done to the satisfaction of the buyer. If it can induce the buyer to avoid reaming or drilling, or planing sheared edges, it can complete its work at a somewhat less cost. It should not be censured when some of the most recent specifications allow this grade of steel to be used in the most important bridge structures at a higher unit stress than usual for soft steel, without requiring a better class of work. Personally the writer can see no reason

why a higher unit stress should be allowed for medium steel than for a soft steel, if both grades are to be subjected to precisely the same treatment in the shops. If higher stresses be allowed for medium steel, then something more is required than merely an increased ultimate strength and an increased elastic limit, and any specifications which increase the unit stress for a medium steel, without at the same time providing for the necessary precautions to insure accurate workmanship and removal of incipient cracks, are taking a stand, which, while probably sanctioned by the manufacturers whose interest it is to cheapen work, should not meet with the approval of engineers who count on every square inch of section in their structures as available material undamaged by shop manipulation. Soft steel, that is, steel between 52 000 and 60 000 lbs., can be treated just the same as iron up to a certain thickness was treated. This is generally admitted. The metal flows easily, it is not liable to crack and will stand an immense amount of abuse, and if the shop punching is fairly well done and all important field connections matched in the shop and reamed, there is no doubt but that the result will be a first-class structure. Mr. Greiner.

What argument can be advanced which will justify the use of a harder metal at a higher unit stress than allowed for soft steel when this harder material has nothing in its favor except a little higher ultimate and a little higher elastic limit? It is inferior in ductility, it is more apt to be brittle, it will not stand the same amount of drifting, bending or other abuse usually required for soft steel, and it is injured to a greater extent than soft steel by punching and other rough shop work. When using a harder steel with a higher unit stress engineers should insist upon treatment and workmanship which will minimize abuse, and, as the author states, there is no bridge shop in existence which can turn out thoroughly first-class work without reaming or drilling.

The probability of increased train-loads in the future, and an occasional blow from derailment, and the continual vibration due to fast speed, all have a tendency to develop flaws or defects invited by rough workmanship. This development may not take place to-day or to-morrow, but who can say that it will not occur the day after? Precautions taken in the interest of safety should not be sacrificed for the sake of a very small fraction of a cent per pound.

In this connection the writer desires to state that, while at the present time he is using both soft and medium steel, the former treated same as iron and worked with a low unit stress, the latter reamed or drilled and a higher unit stress used, he believes that should he have occasion to renew his 1896 specifications, he would specify but one grade of steel, having 60 000 lbs. ultimate with a variation of 5 000 lbs. more or less. He would use soft steel unit stresses for ordinary bridges, and work the steel without drilling or reaming except in im-

Mr. Greiner. portant connections. For bridges having spans of 250 ft. or more, he would use higher unit stresses, and ream or drill all holes, and would consider that the benefit derived from the more accurate workmanship would justify the increased unit stresses for precisely the same grade of material.

Mr. Belknap. W. E. Belknap, Assoc. M. Am. Soc. C. E.—Taking up Section 3 of the paper, which is headed "The Best and Cheapest Kind of Portland Cement to Adopt, and the Best Proportions for Concrete made with Same," it will be found that in the specifications for the "best quality obtainable" of Portland cement, the requirements for neat tensile strength for twenty-eight days are 400 lbs. per square inch. The specifications read, "from 400 to 600 lbs.," but the minimum limitation alone carries weight. The writer ventures to assert that there are quite a number of high-class domestic Portlands that will run, not only above 400, but far above 600 lbs. on a 28-day test, and that it would be the common opinion among engineers that such cements would be much better than a 400-lb. cement. The same criticism is applicable to the requirements for sand briquettes. The writer has no intention of suggesting the requirements for "best" Portland cement, but is of the opinion that while the author's recommendations might secure the cheapest, they certainly do not assure the best.

The value of stating a requirement which ranges between limits from 50 to 150% of the minimum apart is difficult to discern. Specifications should as much as possible avoid compelling verbal explanation. If the engineer's minimum limit for a certain quality is fixed in his own mind, he should state it explicitly and adhere to it. A dealer supplying 600-lb. cement does not ordinarily place himself in competition with a 400-lb. article; and it is quite apparent that under the last clause of these specifications, to secure the chief engineer's approval of his own brand as a "best" cement with any meaning, he must also secure the disapproval of 400-lb. brands. These are specifications which do not specify.

With respect to the author's suggestions concerning concrete for pedestals, the writer is of the opinion that with either graded or uniform-size stone, the voids of the same can be filled with mortar in a one-three-six mixture, and that this is more dependent on the manipulation and subsequent consolidation of the concrete in place than on grading the stone very carefully and thoroughly mixing the various sizes, each of which precautions would probably cost considerable, were they literally carried out as the author suggests.

Mr. W. M. Patton, in his "Civil Engineering," gives the voids in concrete stone as follows:

Uniform size—$2\frac{1}{2}$-in. ring	37.07%
" " 2 " "	39.50%
" " $1\frac{1}{2}$ " "	42.00%

Mr. A. W. Dow, in the "Report of Engineer Commissioner of District of Columbia, for 1896," gives the voids as follows: Mr. Belknap.

Average concrete bluestone	45.3%
Coarse concrete stone	45.3%
Mixture of 1 part average concrete stone, 1 part small gravel	35.5%
Mixture of 2 parts average concrete stone, 1 part small gravel	36.7%
Mixture of 3 parts average concrete stone, 1 part granolithic bluestone	39.5%
Gravel, "average gravel"	29.3%

William M. Black, M. Am. Soc. C. E., in "United States Public Works," gives the voids in screened and washed, piled loose, concrete stone passing a 2-in. ring, as 46.5 per cent. The writer has found the voids in washed gravel of mixed sizes running from $2\frac{1}{2}$ to $\frac{1}{2}$ in. to be 41.0 per cent.

It will be noted that in none of these cases do the voids amount to 50 per cent. Theoretically, therefore, in a one-three-six mixture the mortar would be in excess of the amount required to fill the voids. In the relation of mortar to stone this mixture is almost practically the same as a one-two-four mixture, with which the writer has experienced no difficulty in the matter of filling the voids without taking either of the precautions referred to.

While it apparently stands so in the paper, the writer does not believe that the author recommends an "eminently slow-setting cement" for concrete to be deposited under water.

A combination of Sections 5 and 12 of the paper leads the reader to infer that the only timber used was "vulcanized" long-leaf yellow pine passing "clear" inspection. It is difficult to conceive that a railroad company would countenance the gross extravagance of using the most costly grade of timber when the preservative treatment of cheaper grades would give an article much more economical. The claims of economy set forth by the various preservative companies are based in a large part on the probability of making the inferior grades of timber more durable than the higher grades. In relation to "Vulcanizing," it may be pertinent to quote from a publication* of the Division of Forestry, Department of Agriculture. In this process it is claimed that "the chemical condition of the sap may be changed into a preservative composition" by heating the timbers to "from 300° to 500° Fahr. under air pressure of 100 to 175 lbs. per square inch"; or "by substituting a vacuum for the pressure and a low temperature to effect the same result, namely, to 'vulcanize' the wood. There is no knowledge of the physiology or character of wood to sustain the

* "Bulletin No. 9, 1894," p. 243.

Mr. Belknap. claim of the physical change, nor has the material been long enough on trial to prove by experience the value of the process. Tests of treated and untreated material of such nature as to make the material comparable otherwise, made by the Forestry Division, did not show any increase in strength, as claimed, nor any chemical or physical changes."

In view of this statement of the Forestry Division, which must be given considerable authority in such matters, such data and tests as the author may have contradictory to the preceding would be not only interesting but very valuable, particularly as his figures demonstrate a large economy on the assumption of the process being efficient.

Mr. Cowles. W. L. Cowles, M. Am. Soc. C. E.—The paper is a valuable contribution to the literature on this subject, and is especially commendable in calling attention to the defects in existing structures, and in laying down the broad principle that an elevated railroad should be equal in all respects to the best class of railroad bridges. It would seem that this proposition should need no argument, for, as the author says, the service of the structure is much more constant than that of most railroad bridges, and the maximum load effect is more frequently reached, while the successive starting and stopping, with the attendant longitudinal thrust caused by the braking, calls for special rigidity in its design and the best of shop work in its execution. Surely any accident which might occur through faulty design or construction would not be attended with less serious results than a similar accident to a railroad bridge, while the possibilities of disaster as affecting adjoining property and loss of life in streets, through a collapse of an elevated structure, furnish additional reason for thoroughness.

The selection of material made by the author was doubtless in accordance with the results of his careful investigation, and seems to have been determined upon as giving the most economical construction upon the basis of universal reaming. There is probably little question as to the benefit accruing from re aming all holes in medium steel for the purpose of insuring solid metal around the holes, but the writer is not yet prepared to accept the statement made by the author that all material should be so treated. The author is quite correct in holding that even in the best shops it is impracticable to punch holes to match perfectly, and there is certainly advantage in the riveting if the component parts of members are so assembled that all rivets will enter the holes freely, but this object can be attained by the use of the tapered flexible reamer to which he refers. This he admits, but contends that in such holes the rivets will not completely fill out, and will therefore not act effectively. The writer understands that reference is made to long members, such as chords and posts of a bridge or columns of a building, and, as applied to such members, which constitute a large proportion of the work of most shops, he does not

accept the force of the argument. The effective action of rivets in the body of such members does not depend upon the complete filling of the holes so much as upon the formation of full heads, well closed down upon the surface of the steel, since the office of the rivet is not to transmit shear, but to hold the component parts of the members tightly together, so that the strength of the unsupported portions of any part may in no case be less than the strength of the member as a whole. The rivets in reinforce or pin plates, in brackets on columns, in the ends of the flanges of girders, and in all positions where the full efficiency of the rivets in shear is required, should completely fill the holes, but such rivets ordinarily occur only in comparatively small small portions of a member, and the component parts can generally be so adjusted that these holes will come fair, leaving what mismatching there may be to come in a part of the member where the rivets are not in shear, and where the flexible reamer will accomplish all that is necessary. Mr. Cowles.

The writer is in favor of reaming all holes for field connections, especially where the number of holes is large or the connection complicated, and does not intend to argue for poor workmanship or careless punching, but is of the opinion that while there may be a satisfaction in the consciousness that work is nicely done, the extra expense involved in the sub-punching and reaming of all holes in soft steel and iron is not commercially justified by any benefit derived therefrom. He does not believe that metal work constructed of such material, carefully punched and assembled and well riveted, can properly be excluded from the term "first-class work."

A. C. Cunningham, M. Am. Soc. C. E.—Within the recollection of most members, when an engineer desired to build a structure of steel, it was only necessary for him to specify "steel" of certain physical properties. That he would obtain the product of the Bessemer converter was assured, for there was, at first, no choice or alternative. Some of these first specifications are in use to-day with few or no changes of importance, though far better steel is furnished under them than they were originally intended to cover, owing to improvements in manufacture and increased knowledge. Mr. Cunningham.

Some of this early Bessemer steel, high in phosphorus and sulphur, overdosed with manganese, and filled with oxide of iron, would to-day be branded as a villainous mess. Of the structures made of this steel, many have been taken down, some have fallen down, and the balance will come down in some way in the course of time.

Engineers who were using steel presently had their attention called to another process than the Bessemer by which a better and more desirable product could be made, and which, by the time it reached the structural engineer, had become generally known as open-hearth steel. Where the best results were of more importance than the actual cost,

Mr. Cunningham.

open-hearth steel was now specified, and those whom necessity still compelled to use Bessemer steel made their specifications to read Bessemer or open-hearth steel, with little or no hope of getting the latter.

The deadly enemies of iron and steel have always been and always will be phosphorus and sulphur. Owing to the much greater cost of manufacture of the early open-hearth steel over Bessemer steel, a much better melting stock, lower in phosphorus and sulphur, could be used for the former without much increasing its cost, and to this superior melting stock was largely due the superiority of the open-hearth steel.

The superiority of open-hearth steel to Bessemer being partly due to improved methods which largely increased its cost, and partly due to the use of a better stock which did not much increase its cost, manufacturers of open-hearth steel at once called attention to this superiority of composition in advocating their product. Recognizing both advantages, the engineer who could not avail himself of the first took advantage of the second and began to put limits on the dangerous elements in Bessemer steel, rightly inferring that what would improve the one kind would improve the other. These first chemical limits for structural steel were quite generally confined to phosphorus.

Having discovered that phosphorus and sulphur could be neither utilized nor neutralized to any extent in steel, the steel-maker next turned his attention to eliminating these troublesome elements, with the happy result of developing the basic process of steel making. The mechanical differences between the basic and the older processes are slight, the chemical differences are great. Being made in the same kinds of furnaces and converters as the older steels this new product needed only a qualification to have a name, and was quite naturally called basic Bessemer and basic open-hearth steel.

The acceptance of these terms made at once a family name of Bessemer and open-hearth, and the originals were christened acid Bessemer and acid open-hearth. Specifications reading Bessemer steel or open-hearth steel were no longer definite, since Bessemer and open-hearth steels could each be made by either the acid or basic process.

The original open-hearth steel, now called acid open hearth, is made by a comparatively simple process. The hearth of the furnace is lined with silica, whence the name acid, and on this is placed the melting stock, consisting of pig iron, iron or steel scrap and iron ore. This charge is melted down, the silicon and manganese burn out first, and then the carbon to the point desired by the steel-maker, when the furnace work is complete. If the phosphorus and sulphur burned out also, the basic process would never have been heard of, but unfortunately they do not. Whatever amount of phosphorus and

sulphur was in the original charge remains in the steel. From this the reason for the well-known uniformity of acid open-hearth steel may be seen. The phosphorus and sulphur can be exactly estimated from the original charge. The steel-maker has only to give his attention to the reduction of the carbon to the desired point, and when he has made his manganese additions, the steel is finished. Unless chemical limitations are placed upon the dangerous elements, acid open-hearth steel may be uniformly bad, instead of uniformly good. Mr. Cunningham.

In the basic open-hearth process the hearth is lined with dolomite. In addition to the pig, scrap and ore, the charge contains lime. From the dolomite lining and the lime in the charge comes the name basic. The object of the lime in the charge is to unite with the phosphorus and sulphur, and pass them into the slag. Were lime charged into an acid furnace, it would act on the silica lining in preference to the phosphorus, but in the basic furnace it has no action on the dolomite. The greatest action of the lime in a basic charge is on the phosphorus; its action on the sulphur is much less.

The basic process being essentially a dephosphorizing one, it is possible to use for it a melting stock so high in phosphorus that steel made from the same stock by an acid process would be worthless. The regulation of the carbon becomes therefore of secondary importance to the reduction of the phosphorus to at least a safe limit, and as the carbon may be nearly all eliminated before the phosphorus is reduced, it becomes necessary in most cases to make carbon additions. It is not essential to the success of the process that the phosphorus in a basic open-hearth charge should be large; it may be as low or lower than in a charge for good acid steel, in which case the phosphorus will be nearly all eliminated.

The irregularities of basic open-hearth steel may be best illustrated by assuming a specification, and then seeing what may happen under it. As sometimes happens a specification originally intended for acid steel is applied to basic without change, and as this will give an extreme case, such a one will be taken; ultimate strength, 60 000 to 70 000 lbs. per square inch, phosphorus not to exceed 0.08 per cent.

A cast containing 0.08% phosphorus would require 0.12% carbon to give 60 000 lbs. in ordinary sections, and a cast containing only a trace of phosphorus would require 0.3% to give it 70 000 lbs. under the same conditions. By skilful treatment both these casts may be made to pass the same specification, though they are at the extreme limits. Now, under varying conditions, these two casts will give very different results. The 0.3% carbon cast will be found much more sensitive to heat treatment than the other, and can be hardened to a much greater extent, and correspondingly softened on annealing.

Mr. Cunningham.

Specifications for basic open-hearth steel seldom allow the phosphorus to exceed 0.04% or 0.05%, but they never prevent it from going to a trace, which frequently happens, and if the allowed variation in ultimate is, say, 56 000 to 64 000 lbs., steel having from 0.12% to 0.24% carbon may be found under such a specification.

Such variations as this are not likely to be found in acid open-hearth steel, for, if the phosphorus limit is 0.08%, the steel-maker will not go much below this on account of the increased cost of the raw material. With basic open-hearth, however, the difference in cost between 0.04% and a trace of phosphorus is only the difference of the slight excess of lime required to produce it.

Basic open-hearth steel is naturally a soft material on account of the low point to which the carbon is reduced in the furnace, and if a high ultimate is desired, it must be reached by adding carbon to the steel at the end of the process. Such carbon additions are made by throwing coke into the ladle into which the steel is tapped, and, as this does not always become thoroughly mixed with the steel, some parts are sometimes found to be harder than others.

From the foregoing it may be inferred that several heats of basic open-hearth steel may fill a specification, be of excellent quality, and at the same time of variable composition. Unless sulphur is limited in a specification for basic open-hearth steel, it is possible to get a product which is high in this dangerous element, for it is not reduced to the same extent by the process as the phosphorus.

There are advantages in connection with the basic open hearth which are of great importance, and the principal ones are the possibility of producing a very low phosphorus steel and a very soft and ductile one at a moderate price.

The low phosphorus scrap resulting from the basic process, however, at once permits of a low phosphorus acid steel at a competing price, and when strong steels are wanted, they can be made with more regularity and certainty by the acid process than by the basic, for they do not depend on carbon additions to the same extent, and are, therefore, freer from the possibility of uneven mixing.

When it is desired to make a specification to cover both acid and basic open-hearth steel, it is well to make separate provisions for the chemical limitations at least. For acid steel a limit of 0.08% of phosphorus and 0.06% of sulphur, and for basic steel a limit of 0.04% of phosphorus and 0.05% of sulphur will produce good results and admit of competition between the two steels.

A range in ultimate strength between 56 000 and 64 000 lbs. will cover both steels to advantage. For basic open-hearth alone, 52 000 to 60 000 lbs. will give excellent results, while for acid open-hearth 60 000 to 68 000 lbs. will be found quite uniform and reliable.

C. E. Fowler, Assoc. M. Am. Soc. C. E.—The attention paid to the details of the work, as evinced by the paper, is certainly commendable. Very few realize, however, as can the bridge companies which are doing work under many different engineers, what a great variety of details are considered best. One point that has impressed the writer on most recent work is the tendency to err on the safe side, if such can be called error. Mr. Fowler.

After working under specifications of many of the trunk lines and of many consulting engineers, the writer has adopted in his own specifications soft medium steel, from 55 000 to 65 000 lbs. ultimate, as being the metal that will undergo the manufacturing processes with least liability to damage, and avoid the necessity for reaming.

As most shops get out work at the present time, making a wood templet for each piece in a structure, it can only be extreme carelessness if holes in assembled members do not match well, and it is usual to see the holes match perfectly in girder flanges for the entire length. Compressed air reamers are used in most shops on all work to clean out the burrs and true up holes, thus avoiding the cause of drifting, and saving delay and expense in shop work. It is not usual to use reamers of such great taper as the paper seems to suppose, and practically true holes result. For reamed work where $\frac{3}{16}$ in. is to be removed, twist drills are used, and with experienced workmen work is done which cannot be distinguished from that of fixed machines. The adaptability of such machines to varying conditions in shops is no doubt what commends them to shop-owners.

As to acid and basic steel, the question is being settled by the mill owners, who are preparing to furnish the basic product as against the acid. At one of the largest mills in this country basic steel is being turned out in which it is unusual to find the phosphorus exceeding 0.01%, and the greater part of the output contains only a trace. That this will more than offset any small gain in the uniformity of the product of acid furnaces, which is no doubt due to the better stock used, will certainly be admitted by most users of steel.

As great a problem is presented in what paint to use as in any point in the paper. During the past two years, each engineer has had his favorite paint, one for painting work at the shop and still a different kind in the field. After seeing scores of brands used, the writer has come to doubt if any paint is wholly good or accomplishes its purpose. There is certainly a growing assurance among engineers that linseed oil is not the proper shop coat, and carbon primer is the favorite as a substitute. Experience shows the change to be a wise one, as it forms an elastic covering and is said to act chemically on the surface of the metal. What to do to remove the scale from steel before getting this first coat is a question. Will the mills devise some way to free their product from scale, or will the buyer pay to have the

Mr. Fowler. steel pickled? This is a much greater question than the field coat, as any of a dozen paints are first class for this, with the lead and graphite paints counted best. This coat should always be a different shade or color from the shop coat to make it easy to see when all parts are covered.

That the granitoid caps to exclude moisture from the pedestals are excellent is true, but it is a question if Portland concrete, properly crowned, would not have been sufficient.

The proportions for concrete are such as would give excellent results in practice, and if care is used these proportions would give satisfactory results under water. On some recent foundations, exactly these proportions were used by the writer and the concrete deposited under 15 ft. of water; when the work was pumped out, the concrete was found to be very uniform and set firm and hard. The uniformity was accomplished by depositing it through a tube, the first filling of the tube being accomplished by sliding paper sacks filled with concrete into the tube until above water level. For such work as pedestals, proportions as high as one-four-seven for Portland will be found to give much better results when the voids in the stone do not exceed four-tenths, than the more frequently used one-two-four natural cement concrete.

The limit for plate girders has been much extended, and it is customary for bridge shops to have orders booked for many spans at a time, from 70 to 125 ft. in length, while a few years ago riveted lattice spans would have been used. The usual limit for plate girders does not, however, exceed 90 ft. The great difference in cost is in the cheaper erection of plate girders, as they can be placed in position as complete spans during the intervals between passing trains, as was done on the Cleveland, Akron and Columbus Railway during the past year, where each complete span weighed about 40 tons. The girders were so designed as to go between the trusses of the old Howe truss spans, after the old deck was torn away.

The limit usually adopted for crimping stiffeners is beyond 36 ins. in depth, below which depth fillers are used. Some loss in stiffness is caused by the omission of the fillers, but the same weight of metal could more effectively be added to increase the size of the stiffeners.

Of the columns used, the two channels and one beam would find most favor in a shop, as the Z-bar column is difficult to keep from twisting during the punching and riveting. There is, however, a chance for some person to design a column which will meet the objections to which the different designs are subject, that is, a column where all the rivets are easy to drive, that does not twist so easily in making, and will have more satisfactory methods of detailing, as regards the development of the strength of the column as a whole.

The experiments as to the pressed threads are very interesting, and such threads should certainly be used for many cases where bolts are employed under heavy stress, such as anchor bolts and main connections where rivets cannot be put in. Mr. Fowler.

It is to be hoped that the author will give fully the results of the experiments on angles connected by one leg and star struts, as these are in such general use that the information will be awaited with interest. They affect not only the class of structures under discussion, but more particularly the construction of mill buildings.

It cannot be too firmly impressed on the young members of the profession, that one or two rivets do not make a connection. Even if the rivets are driven tight at the time the work is done, one rivet in a two-rivet joint may work loose and then it is left for one rivet to ward off accident, when, perhaps, the structure has been subjected to heavier loads than those for which it was designed. The writer had supposed that spans of any size where the riveted members did not intersect on centers of gravity was a thing of the past, but a recently constructed riveted bridge of 100-ft. span was seen in a western city, with no attempt made to have the members intersect correctly. This lack of design has become so exceptional, however, that anything of the kind is very noticeable, and most of the bad features of the older elevated roads which are mentioned are, happily, things of the past. While there is much room yet for the improvement of steel structural designs, there is reason for congratulation that there is a constant demand for the best in both material and design.

Samuel Tobias Wagner, M. Am. Soc. C. E.—The question of sub-punching in order to obtain the accurate matching of rivet holes by subsequent reaming is one that, without doubt, is conducive to the best results as far as perfect riveting is concerned, although it has been the experience of the writer that the engineer who assumes that by this means he will obtain good matching of holes together with the removal of the $\frac{1}{16}$ in. of injured metal around the holes will deceive himself. The same experience, however, leads him to believe that no serious injury to the metal will result, even if the higher limits of what is usually specified as medium steel are used. The inaccuracies in the holes alluded to are specially noticeable in the case of long plate girders where the web plates are rolled in long lengths and the chord angles have rivet holes in both legs, the stretching of the metal in the long chord angles producing the trouble. Mr. Wagner.

The writer cannot too heartily agree with the statement that real reaming can only be done with rigid reamers, although in poorly matched holes the removal of the injured metal in the holes will not be entirely accomplished, as would be the case if the reamer were allowed to follow the hole. He has more confidence, however, in the rivet practically filling an irregular hole when the rivet is driven by hy-

Mr. Wagner. draulic power than the author of the paper has. Sub-punching and reaming must of necessity cost more than ordinary punching on account of the extra handling required and the delay in the transit of the material through the shops, and it is therefore simply a question for the engineer to decide as to whether the improved quality of the work is justified by the additional cost incurred. It is the opinion of the writer that for shop-driven rivets, and with soft steel of from say 57 000 to 65 000 lbs. ultimate strength, an ordinarily fair increase in the cost per pound is not warranted. On the other hand holes for field-driven rivets cannot match too well, and even a decidedly increased cost would be warranted in obtaining them. This is, of course, due to the difficulty of obtaining a good rivet in the field when driven by hand.

Railroad bridge work has, on account of the special care which has been given in the past to its designing, represented the best practice in structural work, but the writer agrees with the author that there is no reason why it should stand alone in this respect, and endorses the stand he has taken regarding elevated railroad work. He would even go further, and can see no reason why any structure carefully and economically designed should not receive equally as much care in the requirements of its manufacture. It is to be assumed that when an engineer prepares a specification for any work, he does it in the interest of those paying for the work, and that it has received careful consideration, and should therefore stand after the contract is made. The practice of the contractor speculating upon future changes is much to be deplored, and is a condition of things which should never exist. No changes in the requirements should ever be allowed after the contract is signed unless the very strongest reasons exist for so doing. No alternate bid should in equity be considered unless it is asked for in the proposal.

The use of basic steel is a very pertinent one at the present time, and it would be interesting if the author would give his reasons for limiting the use of this metal. The writer is of the opinion that for most purposes (eye-bars possibly excepted) the basic metal is equal to that produced in an acid furnace.

As to the remarks on cements and concrete, the results arrived at are those specified for the construction of the work on the subway and tunnel on Pennsylvania Avenue in Philadelphia, for abolishing all grade crossings on that avenue, a work costing $6 000 000. The specifications for the Portland cement (which is specified for all stone masonry and concrete) follow, and compliance with the specifications has so far been obtained without difficulty, and in some cases very much exceeded. Attention is specially called to the mortar-box tests, which are regularly taken and have proved of great value on this work.

"The acceptance of a cement to be used in the work shall rest with the Chief Engineer, and will be based on the following requirements: Mr. Wagner.

"*Portland Cement.*—Portland cement shall have a specific gravity of not less than 3, and shall leave by weight a residue of not more than 1% on a No. 50 sieve, 10% on a No. 100 sieve, and 30% on a No. 200 sieve, the sieves being the same as previously described.

"Pats of neat cement ½ in. thick, with thin edges, immersed in water, after 'hard' set, shall show no signs of 'checking' or disintegration.

"It shall require at least 30 minutes to develop initial 'set,' under the same conditions as specified for Natural Cement.

"Briquettes of neat cement, 1 sq. in. in section, shall develop the following ultimate tensile strengths:

Age.	Strength.
24 hours (in water after 'hard' set)	175 lbs.
7 days (1 day in air, 6 days in water)	450 "
28 " (1 " " 27 " ")	550 "
7 " (1 " " 6 " "), 1 part of cement to 3 parts of standard quartz sand	160 "
28 " (1 day in air, 27 days in water), 1 part of cement to 3 parts of standard quartz sand	220 "

"All cements shall meet such additional requirements as to 'hot water,' 'set,' and 'chemical' tests as the Chief Engineer may determine. The requirements for 'set' may be modified where the conditions are such as to make it advisable.

"Mortar taken from the mixing box, and molded into briquettes 1 sq. in. in cross section, shall develop the following ultimate tensile strength:

Age.	Strength.
7 days (1 day in air, 6 days in water), 1 part Portland cement to 3 parts of sand	100 lbs.
28 " (1 day in air, 27 days in water) 1 part of Portland cement to 3 parts of sand	150 lbs."

A comparison of the specifications shows a fairly close agreement in the requirements, the specifications just given being slightly harder to fill.

The specifications for the concrete on this work require the same proportions as given by the author, viz., one part of cement, two parts of sand, and five parts of broken stone, which is not required to be graded.

The question of painting is one deserving of the greatest care, and the results of any experiments must of necessity be interesting. Without entering into detail the writer from his experience warmly recommends the practice of giving the metal a coat of linseed oil before leaving the cover of the mill and after all loose black scale is removed. He believes this to be one of the secrets of the prevention of a large amount of rusting, no matter what priming and finishing coats are applied. These latter coats must of necessity vary somewhat with the locality and use of the structure, while this first precaution he believes to be essential in any structural work.

Mr. Stowell. CHAS. F. STOWELL, M. Am. Soc. C. E.—The safety and longevity of any iron or steel bridge is inversely proportional to the amount and extent of motion in the structure. Motion, as regards structures, may be divided into two kinds; dynamic, or that motion due to and inseparable from the imposition of stress, and physical, or motion of translation, which may or may not be accompanied by internal stress. Except when a bridge is moved bodily off its foundations, no failure ever has or ever can take place except as the immediate result of excessive dynamic motion. As long as a bridge contains metal in sufficient quantity and so disposed as to restrict the dynamic motion within certain limits, its life, so far as is known, will be perpetual; but as soon as the limit is exceeded in any one member, the failure of that member sooner or later is absolutely certain. In former times it was the rule, and even yet the practice obtains to some extent, to proportion bridges for stress alone without regard to motion; and many old bridges were simply statical stress sheets transformed into iron. If in any such bridges the dynamic motion was kept within safe limits it was a happy incident or accident of their construction. It is known now that a stress and section sheet is not a safe criterion of the value of a bridge, and that to insure permanence, not only the stress, but also the motion, must be considered and provided for.

When the earlier elevated structures were built, neither the loads to which they would be subjected were anticipated, nor was the subject of dynamic motion understood, and consequently these structures were soon found to lack both strength and rigidity. Remedies of various kinds have been applied to them from time to time to correct the former defect, but the latter is still obtrusively apparent to any observer. It can hardly be questioned that the life of the Manhattan elevated structure must be a limited one for this reason. Whether the limit is close at hand or still far off can only be judged by those in charge of and constantly observing the structure under its daily task. That such a limit was long ago recognized by its owners appears to be shown by these words of one of its officers published fourteen years ago: "The structure is an iron bridge for the whole length of the railway, miles in length; whether this will have to be rebuilt in ten years or fifty nobody yet knows." * The Chicago elevated structure offers a marked contrast to these older works in that not only strength but rigidity also is considered, and it is the first elevated structure within the writer's knowledge where the latter point has received any particular attention. He does not agree with the author as to the value of sub-punching and reaming. If such treatment is prescribed to cure the bad effect of punching, it is delusive. Solid drilling is the only safe course under those premises. The writer has yet to see any piece

* Report of State Engineer and Comptroller in answer to resolution of New York State Senate, March 20th, 1883.

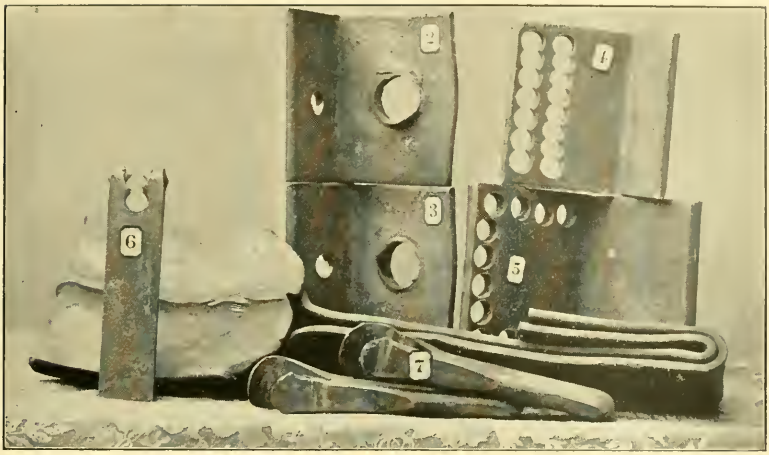


FIG. 1.

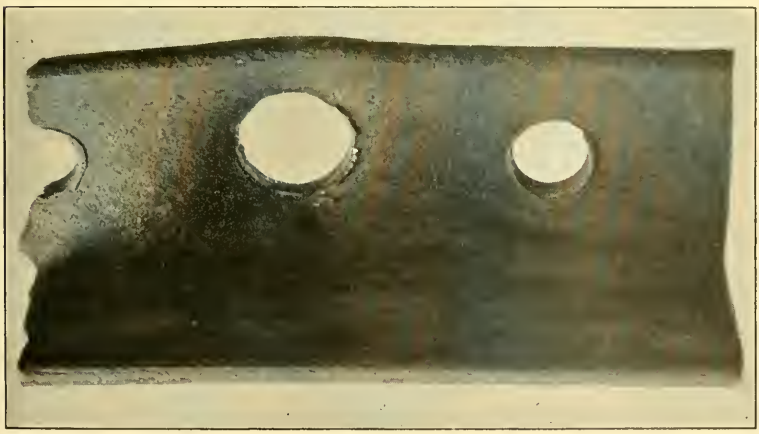


FIG. 2.

of work in which all the punched surface was removed from every hole, and unless it is so removed it is obviously useless to remove it from some and leave it on others. Instead of using material which is liable to injury in punching and then applying a remedy for the harm knowingly inflicted, it seems safer, and it is certainly cheaper, to get in the first place steel which will not be injuriously affected by punching and shearing. Such steel is not hard to get. A photograph, Plate X, Fig. 1, is submitted of some tests on steel of this kind recently used in bridge work, which has stood much more abuse than it could ever possibly get in any shop, and still without reaching its limit of endurance. These test pieces were not specially selected, but were ordinary pieces picked up at random, and the tests were not nursed in the making to produce a fine show, as is sometimes the case, but were actually made in the roughest and hardest manner. This steel was 55 000 to 65 000 lbs. ultimate, averaging about 62 000 lbs. After knowing the quality of this steel from the stock used in making it, from the process of manufacture and from its chemical analysis, and having demonstrated its properties by physical tests, the writer feels perfectly safe in using the material without sub-punching and reaming, and without planing sheared edges; far safer in fact than he would in using an inferior metal and doctoring it afterwards. This particular steel happens to be acid open-hearth, but he has no doubt that basic steel of corresponding good quality would show up equally well. This steel costs from 0.05 to 0.1 cent per pound more than ordinary steel, while the author's figures for the extra cost of sub-punching and reaming are from 0.1 to 0.2 cent per pound. Mr. Stowell.

Reaming for fair holes and not primarily to remove the surface cut by the punch is quite another matter, but with care there need be very little, if any, such reaming done. The author is certainly wrong in saying that no shop can turn out first-class work without sub-punching and reaming or drilling. The writer has been accustomed to specify that when the rivet holes match sufficiently to let a cold rivet through, but not a hot one, they may be drifted fair, but any greater degree of mismatching must be corrected by reaming. In a shop where some care is taken with the punching, the amount of reaming under this specification is exceedingly small. The habitual use of the reamer to get fair holes prevails generally where the punching is piece work. When a man's pay depends upon the number of holes he makes in a day, he is not likely to be over careful where he puts them, especially if he knows some one will follow after him with a reamer to correct his inaccuracies. All this is unnecessary with a little care at the punch. Moreover, the writer is of the opinion that the rivets themselves hold better and are stronger in punched than in drilled or reamed holes.

Another consideration in regard to reaming to remove injured

Mr. Stowell. metal is this. Such holes are always punched in the first place, and often carelessly, as the man at the punch knows they are to be reamed afterwards. Before reaming, the work has to be fitted up and bolted through these punched holes, a process accompanied by more or less heavy drifting according to the degree of inaccuracy in the punching. If the original punching has started a crack in any hole, it will surely be extended by any drifting done on that hole. Can one always be absolutely certain that, whatever the amount of metal reamed out, it is enough to extend beyond the limit of any such crack? The writer thinks not.

One should, of course, use all reasonable precautions to get good and accurate work which will not require abuse of the metal in order to get the parts to go together. If in addition one is sure of having metal which can safely stand far more abuse than can ever possibly be put upon it, should it happen to get any, and which need not be gone over minutely to be sure that every bit of sheared surface has been removed, it is greatly conducive to a good night's sleep.

The steel specification for the Chicago elevated work called for open-hearth metal having an ultimate strength of 60 000 to 68 000 lbs. per square inch; elastic limit, one-half of ultimate strength; percentage of elongation, ultimate divided by 1 500 000 (corresponding to about 25%); percentage of reduction, twice that of elongation; quench bend, 180° around a diameter equal to the thickness of the test piece, and drift test to show an increase of 50% over original diameter of punched hole. The chemistry was prescribed only for phosphorus, which was not to exceed 0.08% for acid, and 0.05% for basic steel. This is a very good specification as far as it goes, and far superior to many in use. But the writer believes that not only the phosphorus, but also the sulphur should be limited. He is aware the manufacturer will claim that, inasmuch as sulphur is a red shortener, it may safely be left alone, as any excess will show itself in the breaking up of the steel in rolling. But this is not all. Experience has demonstrated that sulphur may exist so near the limit of red shortness that, while it does not cause the steel actually to disintegrate in rolling, it may leave the rolls full of minute fractures (micro-sulphur flaws) which cannot be detected by the eye, but which are liable to extend under stress and ultimately cause the fracture of the piece. For this reason the sulphur content should be kept well within the danger limit.

The author's requirement of a drift test showing 50% increase in diameter of punched holes is a good and reasonable one, but too much stress should not be placed on the drift test as indicating the quality of steel. If it does not stand a moderate amount of drifting, the steel is certainly poor, but if it does stand it, it by no means follows that it is good or even passable. The evidence of the drift pin should be considered as corroborative only, not absolute, as is the tendency in

some quarters. There is a bridge specification very widely used and extensively copied throughout this country which provides a drift test showing an increase of only one-third in the diameter of punched holes, and making such a test the criterion for reaming and planing or their omission. To show how utterly worthless such a test is, the writer submits an illustration (Plate X, Fig. 2) of a piece of angle iron with a punched hole drifted from $\frac{13}{16}$ to $1\frac{9}{32}$ ins. diameter, or about 58% increase, and still without reaching the possible limit of drifting. In other words, this piece has filled the requirements of the specification and about 25% more, and under its requirements might be used without reaming or planing for any kind of bridge work under any circumstances. Yet the steel is so poor that the piece shown in the photograph broke off while trying to bend the angle iron to a curve of 40 ft. radius. The peculiar feature of that specification is not only that it lays such stress on this worthless drift test, but, even should the steel be so unspeakably bad that it cannot stand this drifting, still it may be used provided only the holes are reamed and the edges planed. Mr. Stowell.

The chemistry of this piece of steel is as follows: Carbon, 0.130%; phosphorus, 0.101%; sulphur, 0.056%; silicon, 0.040%; manganese, 0.591 per cent.

The analysis stamps the steel as a quite ordinary grade of (probably) Bessemer metal, and on the analysis alone it would be rejected for use in any important place; but the specification mentioned would permit its use for any purpose, as that specification ignores both chemistry and process of manufacture. The writer believes more poor steel has probably been put into American bridges under that specification than under any other ever written, and the reason why it does not more often show itself in failures is because manufacturers generally make a much better quality of steel than that specification would permit the use of. There is, fortunately, a limit to poverty in steel beyond which it does not pay to try to make it. When more than a certain percentage cannot be run through the rolls whole, the cost of such of the product as can be finished more than offsets the saving in the use of cheap stock. The tendency in steel making, too, is in the direction of continued improvement in its quality, and most manufacturers nowadays habitually turn out a pretty fair grade of metal, so that the purchaser under such a specification as is mentioned generally gets now a much better article than he calls for.

The author's experiments on the relative value of angle irons connected by one and by both legs are in accord with facts long known to those familiar with riveted construction. A good many modern specifications stipulate that angles must always be fastened by both legs or the section of one leg only be considered as available for stress. If it were true, or even approximately so, that the strength of an angle iron fastened by one leg is that of this leg only, a great many old riveted

Mr. Stowell. bridges would have broken down long ago, but they persistently refuse to collapse and verify the theory.

The author's design for an elevated structure is, on the whole, a distinct advance over all previous efforts in that line, and the care and study expended on the subject have resulted in a structure which apparently leaves little further improvement possible. The use of solid web girders instead of open web, the large and substantial knee braces at tops of columns, the scientific arrangement of the lateral bracing and the proportioning of columns and anchorages to withstand all possible horizontal as well as vertical loads, are particularly good features; and the writer ventures the prediction that future elevated roads will be largely modeled after this one.

The proposed design for an ornamental structure for city streets is a generally beautiful and tasteful design, unfortunately not likely to be realized in practice soon. There is one feature about it which the writer does not admire, namely, the making of the outlet for drain pipes through animals' mouths. The representation of a beast's head in the act of vomiting is not a pleasing spectacle.

Mr. Connor. E. H. Connor, Assoc. M. Am. Soc. C. E.—The stresses used in the various members under varying conditions, and the unit prices assumed in the comparative designs, and their costs, are all omitted in the paper. The several points mentioned from *A* to *P* should, without doubt, receive due consideration, but the author does not state when he deems the columns "properly designed to provide sufficient strength," etc. The same may be said of many of the other articles. As all elevated railroads in Chicago are having a hard time financially, economy must be a very important factor in a design for that city. Certainly safety must not be sacrificed at any cost, but too much money should not be spent to overcome non-injurious vibrations. Vibrations are inherent in all metallic structures, and should simply be kept within proper limits.

The longitudinal girders used on the Northwestern Elevated road have been carefully designed and are well braced. Lattice girders are more pleasing in appearance, and admit more light to the street beneath. They are not so satisfactory for rigidity and maintenance as plate girders. The cost for 50-ft. spans is about the same. The columns used on the same road were very difficult and expensive to manufacture on account of the large plate, over 6 ft. square, with sectors cut out of the lower corners, on account of the connection taking the longitudinal thrust, with its irregularly cut plates, and on account of the many parts, over seventy in each column, which required the columns to be handled several times in assembling and riveting.

It is proper to allow high unit strains in the metal when the live load, dead load and bending moment are all considered; 15 000 lbs.

per square inch would not be too much for medium steel columns on a tangent. The longitudinal thrust due to an application of brakes on the entire train is distributed by the rails, floor and girders over a considerable length of the structure. If it is considered distributed over a distance equal to twice the length of the train, and carried by the columns within that distance, the longitudinal vibrations would be confined to small limits. Mr. Connor.

Columns of more pleasing appearance and sufficient rigidity can be built more economically of 15-in. channels, flared at the end to receive the stringers directly without cross-girders, than those adopted by the author. The channels may be strengthened near the base by angles when it becomes necessary in long columns.

The maximum fiber stress due to the Northwestern loading, longitudinal and transverse bending, assuming the longitudinal thrust to be two-tenths of the entire weight of a train 200 ft. long, and distributed over 320 ft., or 8 bents, in a column 16 ft. high built of two 15-in., 33-lb. channels would be about 12 500 lbs. per square inch, a perfectly safe stress. The sectional area of this column is less than that of the one used, and no longitudinal tower bracing is required. The saving in columns and cross-girders would be considerable. Such columns have been in use in New York for many years, and are to-day satisfactorily performing their duties, though the vibrations are excessive, some of the details poor and the amount of care given them very small.

The rigidity could be increased by altering and strengthening the details. Longitudinal brackets riveted to the columns and bearing against stiff cross-frames between the stringers could be introduced. The writer sees no reason, however, for discarding entirely the main features which are economical in material and shop labor.

The writer is glad to see the firm stand taken by the author in regard to punching and reaming rivet holes, and is sorry to note that facing the end angles of the longitudinal girders, almost equally desirable, was not required. The additional cost is very small. Such workmanship decreases the factor of ignorance as to existing conditions and permits the use of higher unit stresses.

Henry W. Hodge, M. Am. Soc. C. E.—The paper will undoubtedly be of great advantage in improving the general designs and details of elevated railroad structures, though it is to be hoped that American cities are not to be afflicted with any large amount of such work. Æsthetics in an elevated railroad is, in the writer's opinion, purely a matter of imagination, and such structures cannot but be unsightly and ruinous to the appearance and comfort of any city street. Mr. Hodge.

The writer cannot agree that it is advisable to reduce the ultimate stress on basic steel to 61 000 lbs., nor has it been his experience that basic steel is less uniform in quality than acid. The material for the

Mr. Hodge. Duluth and Superior Bridge was ordered under the following specifications: Ultimate, 63 000 to 70 000 lbs.; elastic, 55% of ultimate; elongation in 8 ins., 22%; reduction, 40 per cent.

The use of either acid or basic steel was allowed, except that acid was required for eye-bars. The acid was not to contain more than 0.08% of phosphorus, or the basic more than 0.04% of phosphorus. No difficulty was experienced in getting material of these qualifications, nor did the manufacturers object to it as difficult to make, and the amount of material rejected for failing to come up to these specifications was so small as to be hardly worth consideration. There was about 1 000 tons of acid steel and 2 000 tons of basic steel, and the maximum and minimum values obtained from all specimen tests, including the tests on material rejected, were as follows:

	Acid steel.	Basic steel.
Ultimate	58 710 to 74 840	51 780 to 76 700
Elastic	31 500 to 46 660	32 600 to 49 100
Elongation in 8 ins.	14.5% to 34.5%	17.5% to 33%
Reduction	25.6% to 63.7%	31.7% to 65.3%
Phosphorus	0.018% to 0.08%	0.007% to 0.036%

Considering there was twice as much basic as acid material, the writer thinks these results show basic steel to be not less uniform than acid. Of course, these values are all extremes from a very large number of tests, and in some cases are caused by hard or soft spots; so while they may not show the average character of the material, they at least show what extreme variations may be found in a large amount of material.

In this structure the metal for the wheel treads of the turntable was required to fill the following specification: Ultimate, 70 000 to 80 000 lbs.; elastic, 50% of ultimate; elongation in 8 ins., 20%; reduction, 35 per cent.

The results of tests on basic steel were: Ultimate, 70 980 to 72 050 lbs.; elastic, 47 240 to 49 150 lbs.; elongation in 8 ins., 24.5% to 27.5%; reduction, 50.9% to 55.2 per cent.

As such a grade of basic steel can be made without greatly increased cost, the writer sees no reason for putting the ultimate so low as 61 000, and would advocate from 63 000 to 70 000 lbs. In the enumeration in the paper of faulty details, it seems to the writer that a number are not details at all, but main principles, as the designer who does not use sufficient bracing between longitudinal girders, or put sufficient rivets in joints, or proportion the chords of girders for bending as well as direct stress, or proportion columns for the horizontal as well as vertical loads, or use bases large enough to carry the loads under columns, is not worthy of the name of engineer. These and several other so-called details are such elementary matters, now so

generally attended to, that it is certainly useless to call any reputable engineer's attention to them. Mr. Hodge.

The writer thinks it unnecessary to increase the theoretical number of rivets in a member, if such number is small, for fear one may be loose, as such a possibility should be guarded against by setting proper valuations on rivet-bearing and shearing. If one started to "guess" how many extra rivets should be allowed at each joint, why trust to figures at all? Gravity lines should intersect in a point, of course, to prevent torsion on the riveted joints.

Nor does the writer see any reason why lacing should not be relied on to carry horizontal thrust in the column, as the lacing is generally on each side of the column, and in most cases has two rivets in each lattice, so it will be necessary for four rivets to be loose instead of one, as stated in the paper, to destroy the efficiency of the lattice. The necessity of giving away material to avoid any such improbable contingency is difficult to see. As to æsthetics, the writer believes that most engineers had by all means better call in an experienced architect to give assistance in such matters, as he thinks such a man's idea would doubtless be a great improvement on the one suggested.

Bernt Berger, Assoc. M. Am. Soc. C. E.—The author states that the results of his examination of previously constructed elevated railroads amount simply to the accumulation of a great mass of information exemplifying "how not to do it." It appears, however, as if he has consciously or unconsciously made use of several features of the older systems of elevated railroads. Mr. Berger.

In all the early elevated railroad structures in New York the columns were anchored to the foundations, and the anchor rods were run through to the bottom and not stopped off in the middle of the mass. The writer does not mean to say that such anchorage is necessarily a point of excellence, but the idea is an old one. The rigid connection of the cross-girders to the posts was used as early as 1878 in the City Hall branch of the elevated railroad in New York. Here the columns are formed of two 15-in. channels latticed and inserted into deep pedestal castings, which are anchored to the foundations. One channel is cut off under the bottom flange of the cross girder, which rests on it, and the other channel extends to the top flange of the girder and is riveted to its vertical end angles. Theodore Cooper, M. Am. Soc. C. E., who had charge of this work during its construction, copied this detail in his design of the elevated structure for the Pittsburg Junction Railroad in 1883, and the same method of connecting the cross-girders to the columns has been used in several other elevated railroad structures.

In Fig. 35 is shown a rigid connection of cross-girders to columns, where the former overhang the latter, employed by Mr. Cooper in his design for the Suburban Rapid Transit Railway in New York in 1886. The channels of the columns are cut off under the bottom flange of the

Mr. Berger. cross-girders, a batten plate extended up on each side of the girder to which are riveted two angles which again are riveted to web-stiffening angles on the girder. This top connection gives all the required rigidity to the structure. The foot of the columns is not anchored to the foundation, but rests on a cast-iron pedestal which raises it above the dirt and moisture of the street. The same cut also shows the expansion pocket. The pocket is particularly strong in the girder seat, the vertical webs of the channels precluding any possibility of undue yielding of the seat and working of the rivets.

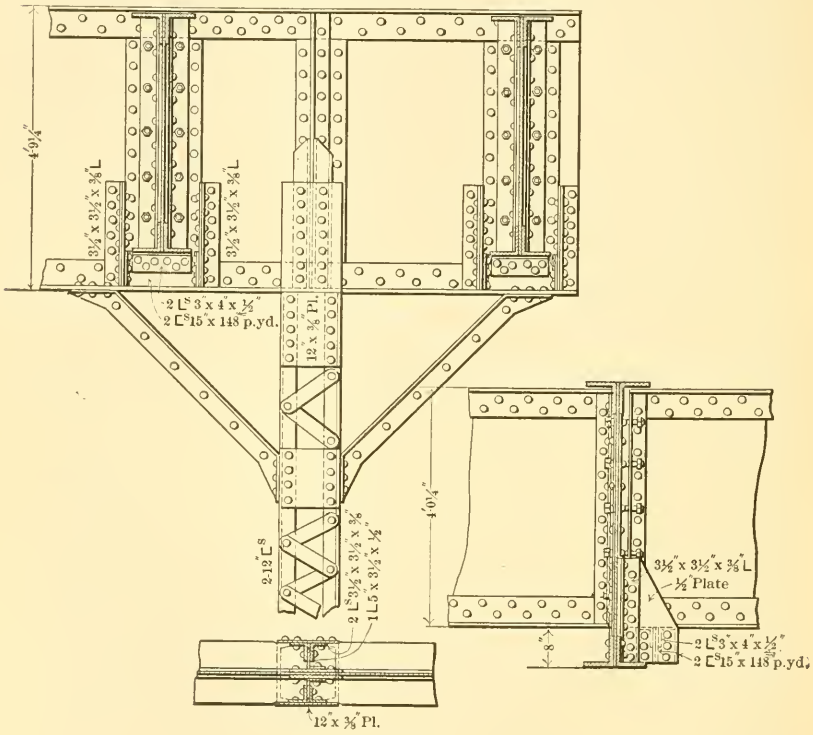


Fig. 35.

Fig. 36 shows the expansion pocket for the railroad stringers of the Asylum Street improvements at Hartford, Conn. This elevated railroad structure was built in 1888, is about 670 ft. long, in part on a curve, and carries four tracks and three platforms. It was designed for Class A of Mr. Cooper's specifications. The pocket is a very strong and rigid one, the side plates and angles having been extended the full depth of the cross-girder. In the same structure stiff transverse sway bracing was used.

Both expansion pockets are provided with $\frac{7}{8}$-in. safety bolts to prevent any possibility of the contraction of the structure under falling temperature becoming concentrated at any one pocket. Mr. Berger.

The introduction of braced towers is admirable, and it is the author's good fortune that his structure was so located as to permit it. The writer is in accord with him in his strong plea for reaming of riveted members, which reaming must, however, by no means be understood to do away with careful work in punching.

Walter T. Smith, Jun. Am. Soc. C. E.—The writer, who was connected for over two and one-half years with the Wabash Avenue ex- Mr. Smith.

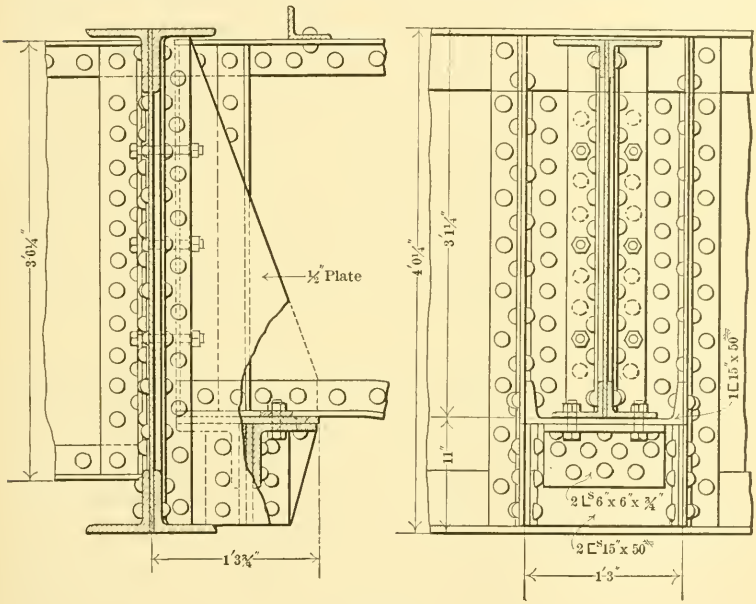


Fig. 36.

tension of the Lake Street road and with both the Northwestern and Union Elevated construction, touches on the following features, not in a spirit of criticism, but rather that some views contrary to those of the author may be noted and corrected if wrong.

The first subject is the radical change over other elevated road construction in the introduction of tower spans, 23 ft. 6 ins. center to center of columns, braced both longitudinally and transversely to the column foot, as shown in the details. The reason given for this is the fact that express trains are to be run over the surface at a rate of 40 miles per hour, making this condition necessary to take the traction force due to the braked train. This assumption was made, evidently,

Mr. Smith. owing to the fact that every fourth span has an expansion joint, thereby making it impossible to direct this longitudinal force into more than four spans or sixteen columns at one time, or at least during the period of maximum stress. This would be true without doubt were the structure proper only to be taken into consideration, but this view does not show all the facts of the case.

The maximum condition of stress is due to a loaded train consisting of one motor car and three trailers, weighing in all about 180 000 lbs., running at the rate of 40 miles per hour. It is found necessary to stop this train in the least possible time. By knowing the distance which the train travels after brakes are applied and the time necessary to bring it to a stop, the calculation of the force of traction or thrust could be made without difficulty. This whole force would be applied to a single section between two expansion joints, owing to the fact that the train length is about 150 ft., while the distance between the expansion joints is, at times, more, were it not for the deck work, and this changes existing conditions totally. In each track system there are four guard rails and two running rails. These six rails form the structure into a mass in such a manner that if a strain is put upon any part of the deck, it is carried over a large extent of its surface. It is true that the space for expansion of the running rail would tend to cause a sliding of that rail were any considerable longitudinal strain put upon it.

In case this sliding does occur, the friction of the spike and tie bearing will convey the thrust into the tie, and from there it must either be taken up by the tie bearing of the girder or by the guard rail. Reason would certainly denote the latter, for the ties and guard rails are bolted together in such a manner as to render it impossible for one to act without the other, while the connection between the tie and the girder is not by any means a complete one, for if such were the case, expansion of the metal would injure the alignment of the deck. This last statement is true to a greater extent of the roads in question than on the Metropolitan Elevated of Chicago, for that road has bolted all ties to the flange of the girder while the Northwestern and Union Elevated use hook bolts on each second tie only.

The conclusion drawn from these conditions is that the stress due to braked trains is not conveyed, to any extent, to the columns. It would be unreasonable to say that this stress does not affect the columns at all, for the fact that the longitudinals and columns are riveted together makes it impossible for one to act without some effect on the other. At the same time no bending can be produced upon the column, for it is counteracted by the deck. Were the longitudinals made continuous for long distances and the only connections with the columns were by bearing plates or rolls, so as to leave absolutely no resistance but that of a body at rest, there would be no direct longitud-

inal motion. This would have a tendency to aggravate the transverse stress greatly, in that it would be continuous, and for that reason, if no other, the author's idea of carrying the columns to the full height of the structure is to be commended. Mr. Smith.

A point of contention might be as to whether the mass of the structure is in stable or unstable equilibrium. The fact that a large body is supported by a column of small area in proportion to its size, or a number of them, does not make it unstable, provided the forces acting upon that body do not tend to move it to a sufficient extent that its own weight is added to the forces already employed. Were the action of the train large enough in proportion to the structure affected to produce a tendency in the mass of the steel to move in the direction that the train travels and thereby lend its own weight to the force of the train, the bending of the columns would be severe. This is not, however, within the bounds of reason and can be at once dismissed. It will be assumed that the action of this longitudinal thrust is wholly taken up by that portion of the structure upon which the train runs, that is, upon two of the longitudinals with the deck. This assumption is greatly on the side of safety, for the design of the structure makes it impossible to strain this one-track system without affecting to some degree the other three, and especially that on the same side of the center. If the force is confined to this single track, however, and its action does not extend more than twice or three times the length of the train in either direction, there is a weight equal to three times that of the train which must needs be set in motion before bending can occur. Were it possible to design a column section in any case, which would carry the load due to compression, without longitudinal strength, then some metal might, in this case, be necessary to withstand any light stress caused by thrust. This being impossible, however, the conclusion is drawn that any metal used in any part of the structure to withstand horizontal thrust in a longitudinal direction is superfluous and a needless expense. This same rule could be applied to the transverse bracing of the towers in a four-track structure. The force of impact is not severe, and the width of the structure makes it perfectly stable. This in no way applies to lateral systems used to stiffen girders, or to cross frames.

The question as to what construction of guards is the most useful seems to be one of great importance and interest to all who are concerned in any way with elevated roads. On the lines under consideration a 6 x 6-in. inner guard is used, while the outer one is 6 x 8 ins. Would not a 6 x 8 in. be better for the inner rail? Without doubt, it is the more important of the two, and should the car jump the track, more lifting power would be necessary to carry it over the high rail than the low. It is true that in case of a blow the high rail would be more likely to split than the low, yet it would seem very doubtful if

Mr. Smith. a blow of that severity could be produced on the inner rail, which is but 4 ins. from the track rail.

The outer guard to a large extent is a matter of sentiment. Its only practical use can be that it stiffens the outer ends of the tie and might in that way prevent a wreck. Could the outer guard be placed far enough from the track rail to allow the entire right wheel of the car to pass over the inner guard before the left wheel struck the outer guard, its practical use would be established. As this is not possible in present construction, the matter need not be discussed. The outer guard, however, lends an appearance of security for the traveling public which possibly warrants its use.

Mr. Treadwell. Lee Treadwell, M. Am. Soc. C. E.—Few engineers will deny the fact that an elevated railroad should be built, not only to carry the assumed live and dead loads, but also to resist the longitudinal thrust of braked trains, the centrifugal force of moving loads on curves, and a lateral force on tangents due to wind pressure and the oscillations of moving trains. At the same time, however, each designer will probably have his own ideas as to how the longitudinal forces should be distributed. Judging from most of the elevated roads now in existence, it would seem that the general practice has been to assume that the track and guard rails make the structure continuous over the expansion joints, and therefore, that the longitudinal thrust of braked trains is distributed over a long stretch of track. It is true that the track and guard rails do give to the structure a certain amount of continuity, but it is an uncertain factor and should not be counted upon, except in special cases. The author's method of treating that portion of the structure between expansion points as entirely independent and separate, and in designing it to resist all the forces that can be applied between those points, is undoubtedly to be commended; in fact it would seem to be the most scientific way of solving the problem. Granting, however, that so far as strength is concerned, the track does make the structure continuous, the author's method would still be preferable, for it leads to the attainment of one of the most desirable qualities in an elevated railroad, namely, that of rigidity.

Again, few will question the author's statement that an elevated railroad should be built with the same degree of excellence in respect to quality of material and workmanship as that of any railroad bridge, and he is probably not going too far when he intimates that it might be well to make the details and connections even more nearly perfect in the former than in the latter. The reason for this is, as stated in the paper, that a railroad bridge will generally receive its maximum live load at comparatively long intervals only, while in the case of an elevated railroad the assumed maximum live load may be applied many times a day. Another reason why the greatest care should be taken in detailing an elevated railroad is that owing to the frequency

of the trains, it is in an almost continuous state of vibration and tremor, which tends to work the connections loose and weaken the structure. Mr Treadwell.

In respect to the use of "unreamed soft steel at a low intensity of working stress, or reamed medium steel at a higher intensity," the author shows his good judgment in his final decision to use medium steel throughout. If, however, it be claimed that rigidity is one of the essential qualities of an elevated railroad, it must be admitted, also, that the use of "soft steel at a low intensity of working stress" has at least one advantage over "medium steel at a higher intensity." The advantage depends on the difference in the unit strains used, for, as the elastic coefficients of the two metals are equal, the deflections and consequent vibrations will be in direct proportion to the fiber strains used in designing. It necessarily follows, therefore, that, everything else being equal, the lower the unit strains used, the more rigid will be the structure.

It is also claimed by some engineers that soft steel is better suited than medium steel to resist suddenly induced strains; and for short-span bridges in particular, the use of the softer metal is urged. The author himself half admits these claims to be well founded. Then, if it be true that the nature of soft steel is such as to make that metal more reliable than medium steel under shocks of greater or less intensity, it would only seem proper under those conditions to strain the two metals about alike, up to, say, 8 000 or 10 000 lbs. per square inch, assuming that the advantage gained in the softer quality of one metal is sufficient to offset the greater elastic limit of the other. If it be taken for granted, also, as claimed by many manufacturers, that the reaming out of the cracked metal around punched rivet holes does not materially increase the strength of the section, and especially its elastic limit, then soft steel would seem to be an ideal metal for an elevated railroad, and there would undoubtedly be a considerable saving in cost by using it in preference to reamed medium steel.

In the writer's opinion most of the advantages claimed for soft steel are entirely problematical, and, except for special purposes, he does not advocate its use. In point of endurance it has been pretty well demonstrated among mechanical engineers that soft steel is far inferior to a higher carbon metal; and there seems to be no good reason why civil engineers should not profit by the experience of their mechanical brethren. Take, for example, car axles, crank shafts, piston rods, and steel rails—how is it that they manage to stand up so well when strained in almost every conceivable way? Does not the chief reason lie in the fact that they have a high elastic limit and ultimate strength? That is certainly the most plausible explanation. It may be claimed that car axles and crank shafts are made of a better quality of metal, which is improved by forging; but, however, that

Mr. Treadwell. may be, the same can hardly be said to be true of steel rails, for they are rolled from Bessemer steel, and have an elastic limit usually not below 50 000 lbs. per square inch. It would seem to follow, therefore, that, other conditions being the same, the capacity of steel to resist indefinitely the application of externally applied forces without injury to itself is measured by its elasticity. The higher the elastic limit, the greater are its resisting powers and the longer will be its life.

Why, then, it may be asked, is soft steel so often called for? One reason is, that some engineers believe it more nearly approaches the nature of wrought iron, and that it is, therefore, more suitable for short-span bridges; in other words, that it is more reliable than medium steel under shocks and suddenly induced strains. As before stated, these claims do not seem to be thoroughly founded on facts. Actual experience with both metals under heavy strain, especially in the field of mechanical engineering, where the wear and tear is more easily observed, is constantly adding additional proof of the inferior quality of soft steel as a durable and serviceable metal.

Another and probably more important reason why unreamed soft steel is so widely favored is due to two facts; first, it is cheaper pound for pound than reamed medium steel; and, second, most manufacturers favor its use because it is claimed to be easier to make and easier to manipulate in the shop. Taken as they come from the rolling mill, there is practically no difference in the cost of the two metals, but in the shop it must be admitted that the softer and more pliable a metal is, the easier and less expensive are the operations of straightening and punching. The difference in manipulation is so slight, however, that most manufacturers will bid the same pound price on unreamed work whether it be of soft or medium steel. Nevertheless, pay the contractor the added cost of straightening, punching and reaming, and he would still rather use soft steel and punch the rivet holes full size, simply because the operation of reaming retards the progress of work in the shop, while his interests require that it be pushed through in the shortest time possible. It is a business proposition that no contractor can afford to ignore in these days of strong competition, especially when there is a large demand for work to be delivered in a limited time. If the manufacturer be paid for the extra work of sub-punching and reaming, it is not clear why he should oppose it on any other grounds than that it reduces the output of his shop. Conditions are changing somewhat, though, and fewer objections to reaming are heard now than formerly. Most of the leading bridge companies are well equipped for drilling and reaming, and they are still making improvements in their equipment along that line. The chief engineer of one of the larger companies told the writer recently that the reaming capacity of his shop was about equal to its riveting capacity.

How much cheaper is the finished product of unreamed soft steel than reamed medium steel? According to the author, the cost of reaming varies from one-tenth to two-tenths of a cent per pound. To illustrate further, suppose bids to be invited on 1 000 tons of structural work erected and painted, first, on unreamed soft steel; and second, on reamed medium steel. The bidders would make less than 10% difference in the pound prices for the two metals. The author states, also, that reamed medium steel may be strained 10% higher than soft steel. Some specifications allow 15% difference. The author's statement, therefore that "as far as the total cost is concerned, it is immaterial whether unreamed soft or reamed medium steel be used," is rather conservative than otherwise in favor of the latter metal. Then there still remains in favor of medium steel the advantage gained in the superior workmanship due to reaming; such, for instance, as the perfect matching of rivet holes in the main members and the consequent better fitting of all the parts. It is self-evident that the more nearly perfect the joints and connections of any structure are fitted together, the more rigid and durable it will be. Mr. Treadwell.

By soft and medium steel, the writer refers to metals having average ultimate strengths of 56 000 and 64 000 lbs. per square inch, respectively. It may be added that no such distinction is observed by the majority of rolling mills. With them, the limits govern rather than the averages called for in the specifications. In specifications for soft steel the ultimate strength is generally limited to 60 000 or 62 000 lbs. per square inch, while for medium steel it is generally required that the ultimate tensile strength shall be not less than 58 000 to 60 000 lbs. per square inch. Here there is a maximum overlap of 4 000 lbs. per square inch. The engineer who wrote the specifications for soft steel could not be persuaded to change to medium, and the designer who called for medium steel would be highly indignant if asked to accept the softer metal instead. The truth of the matter is, however, that many of the mills are daily filling orders for both specifications from practically the same grade of metal. Its ultimate strength averages from 58 000 to 62 000 lbs. per square inch, and as the limits of neither specification are transgressed, both the engineer and the designer are well pleased with what they get.

This practice on the part of the rolling mills of striking an average between soft and medium steel, rather than any lack of uniformity in the basic open-hearth product, is possibly responsible for the facts which led the author to state, that "the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid; and that it may prove advisable in future specifications for basic medium steel to reduce the average ultimate stress limits from 64 000 to 61 000 lbs. per square inch."

Excluding metal rolled for rivets, it is probably safe to say that

Mr. Treadwell. 90% of the soft and medium steel rolled at the present time for structural purposes has an ultimate strength between the limits of 56 000 and 66 000 lbs. per square inch, a range of only 10 000 lbs. which some manufacturers claim should be allowed.

It is possible, then, that authors of specifications are splitting hairs and quibbling over the difference between soft and medium steel to no purpose. It is to be hoped that such is not the case, but it must be confessed that there is some ground for such a declaration. Why not adopt a single standard at once and be done with it? There are three courses open; first, accept and be contented with the present imperfect system; second, retain the distinction between soft and medium steel, but require that the metal furnished shall have an ultimate strength equal to that called for in the specifications, and not an average 2 000 or 3 000 lbs. above or below; third, abandon the distinction between soft and medium steel, and adopt, for all general purposes, a uniform metal of the highest grade the manufacturer can make consistent with the cost, regularity and reliability of the product. At present, an average ultimate strength of from 60 000 to 62 000 lbs. per square inch would probably be about right. It would be necessary, of course, to continue to make rivets of soft steel; and for very long span bridges it would be advantageous to use a higher grade of steel, having an ultimate strength of, say, 62 000 to 70 000 lbs. per square inch, even if the cost should be increased somewhat.

If it were proposed to abandon the present distinction between soft and medium steel, there would probably be a vigorous protest from the engineering profession in general; but, however that may be, much may be said in favor of a single standard for structural steel. In the first place, the difference between the ultimate strength of such a standard and the ultimates now called for in specifications for soft and medium steel would be insignificant when reduced to the corresponding working stresses, especially when it is remembered that authors of specifications differ greatly in the unit stresses allowed in designing.

Again, if a single standard were adopted, the manufacturer would doubtless feel disposed to improve his metal in the direction of a higher elastic limit, and at the same time preserve its uniformity and toughness; but so long as he is required to make both soft and medium steel upon specifications that overlap, so long will the metal produced be neither soft nor medium steel in the strictest sense, but an approximate average between the two. Then, too, if the manufacturer were required to make only one grade of metal, it would naturally be more uniform and regular in quality, which would tend, also, to decrease the cost of manufacture slightly.

In speaking of the relative merits of acid and basic open-hearth

steel, the author states that "the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid." During the last two or three years it has been the writer's privilege to spend considerable time in the shops of some of the leading bridge companies, and, in addition to observing closely the various manipulations the metal must undergo before it is finished ready to ship, he has conversed more or less with those who are familiar with the conduct of the metal at every stage of its manufacture. The information gained in this way, added to the results of the testing laboratory, tend to convince him that the product of the acid open-hearth furnace is somewhat superior to that of the basic furnace, notwithstanding the claims of some of the manufacturers to the contrary. Mr. Treadwell.

In the first place it is perfectly rational that acid steel should be better, for it is more homogeneous in its molecular construction. When properly manipulated, it does not require to be recarbonized. Basic steel, however, is first run very low in carbon so as to reduce the amount of the impurities in the metal, and especially to lower the percentage of phosphorus. It is then recarbonized, and to perform that operation so as to obtain a thorough, complete and even distribution of the carbon throughout every particle of 25 tons of metal in one mass is practically impossible. It must be admitted, though, that such a high degree of perfection has been obtained in this direction that it is exceedingly difficult to distinguish the two metals in the ordinary laboratory tests. If a large number of full-size members were tested to destruction, it is possible that the difference would be more noticeable. For instance, in the test to destruction of full-size eye-bars of considerable length, it has been observed that the stretch as measured foot by foot is noticeably more uniform in the case of acid than in that of basic open-hearth steel. This fact alone would seem to prove that the former metal is more homogeneous than the latter.

With respect to the different melts or heats, however, it is believed that basic steel can be made just as regular in quality as the acid product, and possibly more so. The reason for this is the fact that in case of the former, the quality of the metal can be regulated in the furnace by reducing the percentage of the impurities, and then by reintroducing the proper amount of carbon; but in the case of the latter, the quality of the metal depends on the purity of the stock charged into the furnace. In fact, owing to the oxidation of a certain portion of the iron, the percentage of the impurities in the final product is greater than in the original stock or scrap. About the only thing that it is attempted to regulate in the acid furnace is the percentage of carbon, but if it is run too low in the finish and has to be recarbonized, the product is inferior to basic steel. Probably the best quality of acid steel is that made from basic scrap containing small percentages

Mr. Treadwell. of sulphur and phosphorus, with enough pig iron added to regulate the carbon. In one sense, therefore, acid steel is basic steel refined.

Reasoning along these lines, and not forgetting the results of the testing laboratory, it is difficult to understand how it is possible to produce basic steel superior to or even equal in quality to acid steel, provided the same degree of care and precaution is observed in the manufacture of both metals.

Assuming that acid steel is somewhat better than basic, it is largely a matter of cost whether the difference is great enough to warrant any decided preference being given the former. Acid steel being made principally from selected scrap, its first cost would be considerably increased if there was a large demand for it in preference to basic steel. In view of this fact alone, it is probably more economical in the end to use the basic product, especially if the ultimate strength required is not greater than 65 000 lbs. per square inch. For metal with an ultimate strength above 65 000 lbs. per square inch, the writer would give a decided preference to the acid product.

When it comes to sub-punching and reaming in general, much may be said *pro* and *con*. It is a subject on which there will always be a difference of opinion among engineers and manufacturers. The writer agrees with the author that it is just as essential to ream soft steel and wrought iron as it is to ream medium steel; for, so far as the elastic limit of the metal is affected, one is injured by punching, relatively, about as much as the other. Then, too, it is almost impossible to make long rivets fill punched holes completely, even when the greatest care is taken in heating and driving the rivets. Where the rivets are short, they can be made to fill the holes quite well, if properly heated.

The metal work with the rivet holes punched $\frac{1}{8}$ in. less than the diameter of the cold rivet and reamed to the required size after the several parts have been assembled, or to cast-iron templets, is better than work with the holes punched full size and often badly matched few will deny, but whether it is always better to the extent of the added cost of reaming is a very different question. The writer is in favor of sub-punching and reaming, and particularly so when applied to heavy and important structures, but he does not deem it essential to ream "all metalwork." That high standard of perfection in workmanship might be very desirable, but owing to economic considerations, he believes there is a large class of light work in which it is perfectly allowable and even advisable to omit sub-punching and reaming, at least in those cases where the metal does not exceed $\frac{5}{8}$ in. in thickness, and where the rivets pass through only three or four thicknesses of plate.

It is not practicable to lay down an inflexible rule governing sub-punching and reaming. Each designer will have to depend on his own

judgment in the matter, being guided at the same time by the importance of his structures and the funds at his disposal; but in case of doubt, his decision will always be a safe one if cast in favor of the higher grade of workmanship. Mr. Treadwell.

Probably the most valuable feature of the paper is the illustration, description, and estimate of the weight and cost per lineal foot of each of the thirteen designs worked out by the author. It is interesting to follow the comparison made between the different styles of construction, and to note that the best form, namely, that with braced towers, is the cheapest. One noticeable feature of all the designs is the ample provision of bracing to prevent secondary stresses due to longitudinal and transverse forces. When tower bracing is used, the necessity for fixing the tops of the columns in the direction of the longitudinal axis of the structure is not apparent. Such a fixed condition of the column only augments the temperature stresses without gaining anything in point of strength or rigidity. When the tower bracing cannot be used, however, it is certainly advantageous to fix the columns at both top and bottom.

Another noticeable feature of the author's design is the extension of the columns up to the top of the transverse girders. Whatever may be said against this practice, it certainly has the advantage of greater strength and rigidity. The sections of the columns themselves could hardly be improved upon, at least so far as strength and rigidity are concerned.

Charles V. Weston, Esq.*—The importance of maintaining a high standard in respect to details and workmanship for elevated railroad construction cannot be overestimated, and the writer fully concurs in the author's statement that an elevated railroad structure is just as important as any railroad bridge ever built, because the live loads are frequently applied, and the assumed maximum loads very nearly reached many times each day. The elevated railroad designer should seek to obtain a structure combining the greatest possible rigidity with economic distribution of metal. This cannot be accomplished except by the most careful detailing and excellence of workmanship. Mr. Weston.

Sub-punching and reaming of rivet holes has been rigidly enforced throughout the Northwestern and Union Elevated Railroad work, and the results as indicated in the completed structure have removed from the writer's mind any doubt which may have existed with respect to the advisability of specifying and enforcing sub-punching and reaming for elevated railroad work. Reaming is the only method which will insure an exact coincidence of the rivet holes in the component pieces of the various members of the structure.

The author's statement in regard to the bearing power of Chicago soil seems to the writer to be misleading, and tending to leave the

* Chief Engineer, Northwestern Elevated Railroad.

Mr. Weston. impression that the foundations for the Northwestern and Union Elevated Railroads were designed and constructed for a unit load upon the soil of 1 ton per square foot. The writer has had much experience in excavating and building foundations upon the soil underlying Chicago, and he has seldom encountered, except near the banks of the river, a soil which would not safely support a load of 3 000 to 4 000 lbs. per square foot. At least two-thirds of the Northwestern Elevated Railroad line is located through a sandy district where the soil would safely support loads of 8 tons to 10 tons per square foot. Through this sandy district the foundations were proportioned for unit pressures of 3 500 to 5 000 lbs. per square foot, the actual cost of foundations being greatly reduced below the estimated cost.

Every feature of the detailing of the Northwestern and Union Elevated Railroad structures has been very carefully considered, and the result in respect to rigidity of structure and economic distribution of metal is very satisfactory. If the writer were called upon to participate in the design and construction of another elevated railroad, he would not deviate from the principles which have been followed in the design of the Northwestern and Union roads in Chicago. One detail of these designs he would change, viz., the position of the top chord of the longitudinal girders, with respect to the top chord of the cross-girders. As shown on the drawings, the top chord of the cross-girders projects from 1½ to 3 ins. above the top chord of the longitudinal girders. This detail seriously interferes with the uniform spacing of the track ties, and will increase to some extent the difficulties of renewing the track. Track girders should project at least 1 in. above cross-girders, which insures absolutely uniform spacing of the track ties. When one reflects on this subject it is seen that the entire structure of an elevated railroad, from the foundation to the top chord of the track stringers, is expressly built for the purpose of obtaining a perfect track, and the importance of preparing an absolutely unbroken surface for that track is apparent.

Mr. Lindenthal G. Lindenthal, M. Am. Soc. C. E.—Three points occur to the writer in reading the paper. They are in connection with the stairways, station platforms and the æsthetic considerations.

The subject of proper stairways does not fail to impress itself forcibly on every passenger. To the writer's knowledge there is not in this country a single elevated railroad, including the one that the author designed, of which the stairways are proportioned with thought of real comfort in ascending or descending them. The daily blockades in the stations during the rush hours testify to it. The cause for them is plain. The average person, leisurely walking on the level, covers about 30 ins. with each step. To prevent a blockade, that horizontal velocity should be maintained on the stairway during the descent or ascent of about 20 ins., equal to about three stairway steps.

The leg motion for that purpose would have to be three times as fast on the stairway as on the level, involving some athletic skill of which the average passenger is not possessed. Hence the blockade. The proper remedy for it is to make the stairway three times as wide as the passage at the top leading to it, so that the crowd on descending can spread out sideways. The broadest stairway should always be provided for. It should not be more steeply inclined than in the proportion of two horizontal to one vertical. A very convenient proportion is $6\frac{1}{2}$ ins. rise to 13 ins. tread. On all the elevated railroads the stairways are much too steep, and in wet and frosty weather positively dangerous. Mr. Lindenthal

One of the worst examples of badly proportioned stairways was in the first elevated Broad Street Station of the Pennsylvania Railroad in Philadelphia. The first week after completion, so many persons fell down stairs, threatening the railroad company with suits for damages, that it was found necessary to build over the narrow marble steps wooden stairways with less slope and a more convenient proportion of rise to tread. The stairways in the present Broad Street Station are very comfortable and properly proportioned, and good examples of what stairways should be for large crowds.

The separation in the station of the incoming and outgoing passengers is not dwelt upon by the author with sufficient emphasis, although his stations show an attempt to meet that requisite. In nearly all railroad stations and in all elevated railroad stations in the East, the incoming and outgoing passengers are in constant collision. It shows a discreditable want of forethought and study.

Making the trains and tracks noiseless, or nearly so, should be one of the principal concerns of the engineer, whether the law requires it or not. That it must necessarily add to expense, as the author intimates, is a view which the writer does not share.

In mentioning æsthetics in connection with engineering structures, the author touches a subject little appreciated by many engineers. It may be that because the conception of beauty never was and never will be one capable of precise definition, that the engineering mind, accustomed to dealing with concrete matter in precise and scientific ways, has become incapable of judging good architectural appearance in connection with structures. Some engineers' ideas of beauty are running to curves and those of others to straight lines; some claim any structure to be beautiful which is properly proportioned in strength and otherwise well adapted to its utilitarian purpose, and others desire their constructions to be called beautiful, conceived as tools doing their work, and to be classed presumably in the same architectural category with crowbars and wedges. The confusion of ideas of beauty is clearly apparent in what the author says on this point: "the extra cost of decorating an elevated structure is con-

Mr. Lindenthal

siderable," and as proof thereof plans of an elevated railroad of that supposed higher architectural order are shown, in which riveted railing brackets are hidden under ornamental cast-iron consols, resting on air, in which supremely superfluous arches are abutting against slender posts, set off with Moresque caps and pedestals, in which the panels are fitted up with (in such place) meaningless scroll work, and in which lions' heads are impaled on the ends of water spouts. No wonder that projectors of good taste and sense should refuse to grant a dollar for this kind of æsthetics.

It is unfortunately a frequent fact that prominent engineering structures, after having their proportions and lines fixed with the usual inanity and indifference to harmonious and pleasing ensemble, are handed over to some decorator, who is to make it artistically acceptable, according to the amount of money that the owners may be persuaded to spend on so-called æsthetics. There are some such examples in New York, and there are to be more in one or two projected large bridges.

The author should be credited for also saying: "The careful designer can generally manage to make his construction more or less sightly, without adding materially to expense." To which should be added, that it is the essence of the highest engineering skill to give a construction a pleasing appearance and agreeable character, without the addition of unnecessary parts and with the simplest means.

Without skill and thoughtful study a perfect work in that respect cannot be designed. The road to perfection is here, also, from the complicated and unsightly to the simple and æsthetically correct. Intimate knowledge of manufacturing methods is as essential for exercising that skill as freedom from construction and manufacturing bias. For the want of the latter condition, an architecturally meritorious design for an engineering structure may not readily be expected to issue from a manufacturing or contracting establishment.

The author invites criticism as to whether he succeeded in giving the structure for the Northwestern Railroad in Chicago a pleasing appearance. The writer will point out merely for illustration one feature. For every five or six spans there is a braced bent with shallower girders and with stout diagonals to afford longitudinal rigidity. With the technical reasons for this arrangement the writer fully agrees, but the break in the continuity of the beam or girder line at the bent is decidedly unsightly and unnecessary. The observer, except he be a bridge specialist, is not acquainted with, and does not care for, the finesse of bending moments and shearing strains, which prompts the utilitarian engineer to use a shallower girder and to break the continuity of line. It is too unimportant a reason to the beholder, who experiences the disagreeable sensation that something is the matter with the superstructure at that bent. He can readily understand the

purpose and admit the propriety of the bracing every four or five spans, but to his mind uniform strength of the roadway in this structure requires uniform beam height. The unity of appearance is violently interrupted to save a few dollars' worth of iron, which if not saved makes the structure so much stronger and evidently better looking. No amount of cast-iron ornamental brackets and scroll work, put on by a decorating architect, could make up for such fault of the engineer, if a high æsthetical structure, of the kind before mentioned, were to be made of it. Mr. Lindenthal

Another unsightly feature, not difficult to avoid, is the track with the ties sticking out into the air, and giving the structure a ragged and uncouth appearance.

The natural black gray color of iron gives the impression of a strong and serious material, the appearance of which cannot be improved by colored paints. Preserved by oiling and varnishing, the natural color of iron is an essential part of its æsthetical appearance. Dust and rust are easiest discovered on it, and therefore most easily guarded against by timely repairs or reoiling. In rare cases, a colored paint may be more suitable, as for instance in wire cables covered with white paint. They absorb less heat from the sun and appear of larger diameter than with a dark color. Some parts of the New York Central Railroad viaduct on Park Avenue in New York are good examples of simple unadorned iron architecture, although in other respects it is not commendable, as it is atrociously noisy.

In connection with æsthetics in engineering structures it is opportunely interesting to note what the venerable German savant, Prof. Reuleaux, said in his well-known blunt manner in a recent paper* on modern bridge construction.

"I do not regard in proper taste extra ornamentation or attached decorative features, or style subsequently furnished by an architect. By architectural designing, I mean the choice of the principal forms, the disposition of the masses, the arrangement of the lineaments of the structure.

"We are asked to call (*das zweckmaessige*) the suitable or fitting for its purpose beautiful; if this be so, we would have to regard a human skeleton as beautiful, because it is adapted for its purpose in a wonderfully high degree. But it does not give us the sense of beauty; on the contrary, it only fills us with aversion.

"The objection to this criticism might be made that the skeleton has no life, and that it lacks the rounded outlines of living flesh. But if in this respect the suitable to its purpose were always beautiful, then we would have to admit that a Hottentot Venus is beautiful; she is healthy, and she is not lacking in flesh, which we miss on the skeleton, and her build is eminently suitable, in that the dusky mother carries on her posteriors, projecting 30 cms., her youngest offspring, nourishing it at the same time. I doubt very much whether even the defender of the utilitarian will claim beauty for her on that account.

* See *Glaser's Annalen*, February 1st, 1897.

Mr. Lindenthal

"We old scholars belonging to the past call that beautiful in a being or in a structure which shows a certain harmonious combination of intellectuality with matter. In that way we have inherited through ages a conception of beauty which is not easily defined by words, but which anyone may appreciate, although he may not be able to create it."

Mr. Pegram.

GEORGE H. PEGRAM, M. Am. Soc. C. E.—The writer agrees with the author that medium steel with reamed holes should be used in preference to soft steel without reaming. Indeed, it would be better to require reaming all punched holes in steel which is to be placed in structures where it will be highly strained or liable to receive blows. If the object is to get fair rivet holes rather than to remove the injured material around the hole, the rigid reamers recommended by the author are, of course, preferable, but the flexible reamers will remove the injured material more uniformly about the axis of the hole, and, the writer believes, will give generally good results.

An elevated railroad structure should be of the best character of bridgework. Elevated roads are always built where the ground is valuable, and proper economy would seem to demand a two-column bent in preference to one of four columns, in order to leave the ground available for other uses as far as possible. This would also apply to braced towers. They no doubt give stiffness to the structure in a much cheaper way than any other, and where the ground can be spared for this purpose it is well to use them; however, experience shows that they are not necessary.

The writer has always believed that cross-ties are out of place on an elevated structure. On the ground, where they are necessary to distribute the weight over the surface, they have proved the best construction, but they are not needed for this purpose on an elevated road, and their effect there is to darken the street below, to intensify the noise, increase the labor of cleaning the structure, and lead to unpleasant drippings after a fall of snow or rain.

The writer submits in Fig. 37 a drawing of the superstructure of the Kansas City elevated road designed by him and built in 1886, in which the rails are carried in iron troughs which also acted as the top chords of the trusses. These channel chords serve also as guard rails, and in case of breakage of a wheel or similar accident, are in effect parallel skids on which the trucks, which should be provided with bolsters located but little above the tops of the channels, might slide. In order to take up as little of the street as possible, the spans were made about 50 ft.; the total weight of steel per lineal foot is 478 lbs. Pin connections were used in this structure, as it is the writer's belief that a structure with much less ugliness and obstruction of light can be built with pin connections. It can be also strengthened with less injury to the remaining parts, and experience has shown that, where properly designed, it is quite as durable. The writer submitted a plan similar to this for the Hoboken elevated road in 1883.

Mr. Pegram.

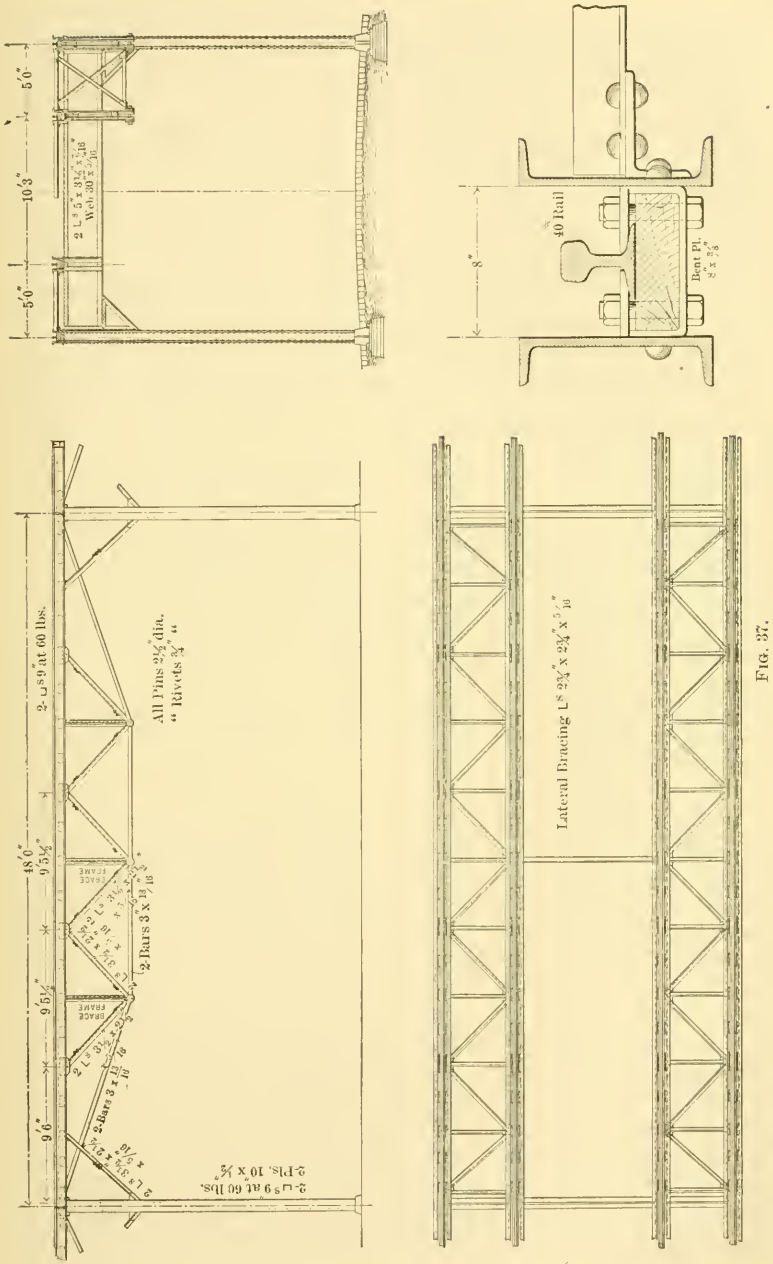


FIG. 37.

Mr. Gates. C. L. Gates, M. Am. Soc. C. E.—Regarding medium versus soft steel, the writer's experience would lead him to prefer soft steel punched over medium steel reamed if the difference in unit stress is assumed at 10 per cent. While it may be right to select medium steel for structures under light traffic, such as that imposed by street railroads, as recommended by the author, the writer does not favor any extensive use of this grade of metal for ordinary railroad traffic except for truss members of long spans which take their maximum stress gradually, and certainly never for short girders subjected to the heavy pounding and vibration of heavy freight trains. The more liberal distribution of metal at a low unit stress seems to be more desirable, and the softer steel more preferable than the more brittle and higher grade of steel; and, if there be any need of reaming at all, by all means let all work be reamed, especially when the thickness of metal exceeds $\frac{3}{4}$ in.

As a matter of economy, there may be a leaning toward medium steel at a high unit stress for structures located at a great distance from the points of manufacturing and center of distribution; but for the Central States, soft steel at a low unit stress will no doubt be used in the future.

Greater care is taken by shop men in matching rivet holes of component pieces of long members, when they know the work is not to be reamed, than when the requirements of specifications call for reamed work. In the former case, if punching is done by piece work the reaming over of misfits has to be done by and at the expense of shop men, and thus they find it to their interest to do good work. With the multiple punch and spacing table very accurate work is done in the shop the writer is connected with, so reaming can generally be dispensed with, notwithstanding the assertion of the author to the contrary.

In this connection, the writer would assert the prediction that for the bridge structure of the future, if not of to-day, good specifications will require that every piece of soft or medium structural steel, and certainly all subject to tension in the finished member, shall be thoroughly and uniformly annealed after the process of straightening and punching has been completed and before riveting is done, for obvious reasons.

As regards the use of basic open-hearth versus acid open-hearth steel, it would be profitable for the profession to hear from the steel-maker direct on this subject. While some inspectors are inclined toward a preference for acid open-hearth steel, owing to the apparent higher elastic limit, yet it must be admitted that in accepting acid steel a minimum of 0.08% of phosphorus must be conceded, while for basic steel it is safe to specify as low as 0.05% for phosphorus, and one can generally rely on obtaining as little as 0.02% or 0.03 per cent. Phosphorus being known as the great enemy of good steel, especially in

cold climates or where it is subject to sudden changes to very low temperature, this fact alone, in the writer's opinion, should lead to the more general preference of basic open-hearth steel, more particularly when the market price of the product is taken into consideration. Mr. Gates.

Referring again to design, the author has certainly shown a happy solution in solving in an economical manner the problem of bringing wind stress or train vibration to the trestle posts, thus relieving the generally much-abused end beam from excessive longitudinal bending strain. The writer does not agree, however, with the author's preference for the four-post bent for a four-track railway. All bents of an elevated railway must necessarily be an obstruction to the established street traffic at the lower or ground grade, and a four-post bent certainly offers more serious objections on that account than a two-post bent; this is slightly intensified when first cost is in favor of the two-post bent. Another objection to the use of a four-post bent is that the foundations of the four pedestals are liable to different settlements under load, thus causing ambiguous stress in the main beam, for which this member is not generally proportioned.

A. T. Tomlinson, M. Am. Soc. C. E.—The author has evidently given much thought and study to the several designs for elevated railway structure discussed in his paper. The design adopted was chosen entirely on account of its superior rigidity, adaptability to the different conditions to be met and æsthetic effect, and without regard to the difficulties which would arise in laying, and later on, in maintaining, the track. Mr. Tomlinson.

In the designs chosen for both four-track and two-track structure, the transverse girders project above the longitudinal stringers from $\frac{3}{4}$ in. in the double-track to 3 ins. in the four-track. This is not a material objection on straight track, but it will be readily seen that on curves where it is generally impossible to set all the transverse girders radially, and where frequently some of the transverse girders make very acute angles with the center line of the track, the conditions are bad. The ties must be laid parallel to the transverse girder, or if laid radially, they will have to be fitted over the transverse girder, materially damaging the tie and rendering replacement very difficult.

The author's original specifications called for 6 x 8-in. ties laid flat and spaced 14 ins. center to center. This was changed on the first track laid on Lake Street from Market Street to Wabash Avenue, to 15 ins. center to center, in order to bring the ties out even at rail joints. This track was laid without tie-plates. After the adoption of the Servis tie-plate, the spacing was increased to 18 ins. on straight track, retaining the 15-in. spacing on curves and cross-overs.

The objection to wide spacing of ties, and the author's reason for specifying 14-in. spacing, is that in case of a derailment there is a strong tendency for the ties to bunch. This, in the writer's opinion,

Mr. Tomlinson. is not a valid objection, as the ties are firmly bolted to the longitudinal stringers, and each tie is securely bolted to two of the four guard rails, to the inside and outside guards alternately. Many elevated railroad accidents have come under the writer's observation, but in none of them has he known the ties to bunch.

By spacing 18 ins. instead of 14 ins., a saving of 22¼% is made in ties, tie-plates, spikes, bolts, washers, etc., which is no inconsiderable item, being at least $1 000 per mile of single track for ties alone, and probably $1 000 more per mile for fittings and labor of laying track, to say nothing of the eventual cost of replacement.

The lumber used in the track is long-leaf southern yellow pine, vulcanized. The writer thinks a mistake was made in specifying that absolutely no sap would be allowed. In the first place, if 1 in. of sap wood had been allowed on two corners of the ties, guard-rails and heavier joists, the cost would have been reduced, but more important than this, is the fact that in almost every piece of dimension lumber, the heart of the tree and center of stick are generally coincident; consequently, whichever side is laid downward, the upper side checks badly. Had a small amount of sap been allowed, the heart side could always have been laid downward, and splitting on account of weather have been reduced to a minimum.

The author originally specified an 80-lb. rail in which the metal was distributed as follows: Head, 47%; web, 20%; flange, 33 per cent. The rail finally adopted was one which was already standard on the Lake Street Elevated Railroad, and known as No. 8001 in the Illinois Steel Company's book of rail sections. This section varies but slightly from the standard 80-lb. rail, designed by a committee of the Society, and having the metal distributed as follows: head, 42%; web, 21%; flange, 37 per cent.

In the track now being laid on the Union Elevated Railroad, and to be laid on the Northwestern Elevated Railroad, 60-ft. rail will be used, connected by Weber rail joints, using four ¾-in. Harvey grip bolts, the joints suspended and breaking even, except on curves, where the joint of one rail is placed as nearly as possible opposite the center of the other rail.

Mr. Rowe. Samuel M. Rowe, M. Am. Soc. C. E.—The Northwestern Elevated Railroad Company directed experiments to be made to test various paints as to their relative ability to protect metalwork against atmospheric action, and particularly against the gases produced by the combustion of coal, with which the atmosphere of the city is more or less pervaded. Each paint was tested by applying it to four steel plates, three coats on each plate. Some of these were exposed to smoke and steam from locomotives, and others to the smoke of bituminous coal in a box prepared for that purpose. Neither of these methods were carried on long enough to furnish decisive results, but the condition

of plates exposed to the atmosphere was observed at intervals during a period of two years. Mr. Rowe.

The dark mineral paints were found to retain their color best, the effect of the weather on the oils being less than where lead and zinc were used as pigments. The use of graphite with white lead and zinc apparently gives the most permanent light shade.

In determining the adhesion of paint to metal, a toothed chisel was found advantageous. The blade is $\frac{3}{4}$ in. wide, one-half toothed with $\frac{1}{32}$-in. notches, $\frac{1}{16}$ in. apart, and the other half with $\frac{1}{64}$-in. notches, $\frac{1}{32}$ in. apart. If the paint is loose or easily parted from the metal, this will be at once manifested if it is attempted to shave a strip of the paint from the metal; the surface of the latter will be free from paint and show any rust spots which may have formed in consequence of the damaged condition of the covering. If the paint is very brittle, the whole surface will be stripped clean, whereas if it is tough, elastic, and clinging closely to the metal, each notch in the tool will leave a fine, continuous line of paint.

The durability of paint and the thoroughness of the protection it affords to the metal depend largely on the resistance of the surface and body of the paint to the action of the weather. If the surface changes or loses its density, the body of the paint will soon do the same, and the whole become porous, absorbing moisture and opening a way for rust. The best degree of elasticity and toughness in the paint seems to be that which will prevent breaking or checking by alternations of the temperature to which it is exposed and from the usage to which it is subject. A tough, elastic paint will roll before the tool and form a wad which will feel like soft leather when rolled between the thumb and finger. A hard, brittle paint will crumble into dust.

Some of the paints tested were soft and sticky when exposed to a summer temperature after the lapse of two years, a condition undesirable in any paint except one exposed to a combination of locomotive steam and smoke, one of the most destructive agents to be withstood. Some of the Chicago viaducts suffer severely from this action, the metal of the lower chord and floor systems being eaten away so rapidly as to require the renewal of these parts long before the less exposed portions of the structure are affected materially. In such cases anything that will withstand the action of the gases on the metal is invaluable. Neither time nor means were available to analyze these paints to determine the cause of the different results, but it has been suggested that the use of animal fats with the oils may produce the softness mentioned, while insoluble or very refractory gums of some kind may help to produce toughness and firmness, when combined with linseed oil.

The asphaltum paints harden like glass forming a surface which seems to resist the action of the coal gases perfectly, but they are liable

Mr. Rowe. to check and do not cling to the metal, being easily broken and separated from it. The Eureka paint used by the author on the Wabash Extension structure covers and clings well to the metal, holding its color fairly, but when shaved with the testing chisel, it is hard and brittle, and seems to some extent porous and likely to absorb moisture.

The author's suggestion to give one coat of linseed oil to all work before it leaves the shop is a good one, and a complete immersion of each piece after it was thoroughly cleaned would be still better. By this means parts would be reached which will be inaccessible for painting afterwards.*

The question of the bearing qualities of the soils in Chicago, with reference to foundations for an elevated railroad, is one that requires investigation somewhat in detail, as there is a great variation in its character in the different parts of the city. That district traversed by the Union Loop, Wabash Extension, South Side Rapid Transit and part of the Northwestern elevated lines, consists of sand, gravel, or both in varying quantities, while part of the Northwestern elevated and almost the entire extent of the Lake Street elevated lines cross a section where the underlying formation on which the piers rest is a plastic clay.

The country on which Chicago is built is almost as level as the lake itself, and only 6 to 15 ft. higher. At the level of the pier foundation, it is almost invariably saturated with water. The presence of water pipes and the slight settlement of elevated structure foundations on them have been found to contribute still further to the difficulties encountered. Where sand and gravel are found, the presence of the water does not materially affect their bearing qualities; but in the clay, failure in many cases is complete, the pier being sustained by the adjacent structure and swinging like a pendulum, distorting and tearing the plates and riveting of the structure.

In consequence of the early failure of many of the pier foundations on the Lake Street elevated line some tests were made. The general practice seems to have been to make the base of the pier about 7 ft. square, equal to 49 sq. ft., giving a pressure of about 20 lbs. per inch. The testing appliance consists of a square wooden block or foot piece laid upon the soil to be pressed, its upper surface being armed with a cast-iron plate with a socket to receive the pivot of a post on which the loading is placed; and a post provided with cross-arms and a platform to receive the loading, and a pin and guys at the top to hold it in a vertical position. The loading consists of pig iron, the pieces of which weigh as nearly as may be 80 lbs. each, to facilitate the estimate of the amount of loading. The compression from

* Mr. Rowe has tabulated the results of his tests of paints of various brands in a statement which is on file in the Library of the Society.

the loading is taken with an engineer's level, the rod being placed on the cross-arms, and readings noted at each addition to the loading. Mr. Rowe.

There were but three tests made, and these were secured only by persistency on the part of the consulting engineer.

In the first test the clay was tested at a depth of about 7 ft. below street grade or $5\frac{1}{2}$ ft. below the original surface. The clay was in its original condition, and was a plastic yellow mass mottled with a blue or slate color, and wet to full saturation. The wooden foot plate was 18 ins. square.

The following is a synopsis of the results:

Load.	Load per square inch.	Compression each loading.	Total compression.
1 500 lbs.	4.6 lbs.	0.000 ft.	0.000 ft.
3 500 "	10.8 "	0.009 "	0.009 "
5 500 "	17.0 "	0.008 "	0.017 "
7 500 "	23.1 "	0.018 "	0.035 "
9 500 "	29.3 "	0.018 "	0.053 "
11 500 "	35.5 "	0.052 "	0.105 "
12 000 failed by sliding cornerwise.			

The second test, also in clay, under similar circumstances, except that a foot piece 2 ft. square was used, gave the following results:

Loading.	Load per square inch.	Compression each loading.	Total compression.
1 500 lbs.	2.6 lbs.	0.000 ft.	0.000 ft.
3 500 "	6.1 "	0.027 "	0.027 "
5 500 "	9.5 "	0.001 "	0.028 "
8 200 "	14.2 "	0.005 "	0.033 "
9 500 "	16.5 "	0.004 "	0.037 "
11 500 "	20.0 "	0.002 "	0.039 "
13 500 "	23.4 "	0.004 "	0.043 "
15 500 "	26.9 "	0.007 "	0.050 "
17 500 "	30.2 "	0.011 "	0.061 "
19 500 "	33.7 "	0.013 "	0.074 "
21 500 "	37.2 "	0.019 "	0.093 "
23 500 "	40.8 "	0.029 "	0.122 "
25 500 "	44.2 to complete failure, the block tipping slightly cornerwise as before.		

The third test on the Wabash Extension was made in the bottom of a pier foundation pit at about 1 ft. below the original ground surface, the soil being an extremely fine, clean sand, the depth of which was not ascertained, but assumed to be several feet, the sand being so exceedingly fine as to be taken for clay at first sight.

Mr. Rowe.

The foot block used was the same as in the second test.

Loading.	Load per square inch.	Compression each loading.	Total compression.
1 500 lbs.	2.6 lbs.	0.000 ft.	0.000 ft.
7 500 "	13.0 "	0.003 "	0.003 "
9 500 "	16.5 "	0.003 "	0.006 "
11 500 "	20.0 "	0.003 "	0.009 "
13 500 "	23.4 "	0.003 "	0.012 "
15 500 "	29.9 "	0.003 "	0.015 "
17 500 "	30.2 "	0.003 "	0.018 "
19 500 "	33.7 "	0.003 "	0.021 "
21 500 "	37.2 "	0.003 "	0.024 "
23 500 "	40.8 "	0.003 "	0.027 "
25 500 "	44.2 "	0.004 "	0.031 "
27 500 "	47.8 "	0.005 "	0.036 "
29 500 "	51.2 "	0.005 "	0.041 "

It will be seen that in the first two cases the compression was accelerated at about 20 lbs. to the square inch, and in the third case at about 40 lbs. In the case of the first two tests 20 lbs. is the pressure at which the clay begins to flow, and may be safely called its ultimate bearing strength under a static loading. In the third test, however, the flowing could hardly have commenced at the point of acceleration, but it must have been due to a softer, less stable stratum a few feet below. Hesitancy to incur any further expense in this investigation prevented any examination of this subject.

Loading at 20 lbs. per square inch is probably entirely safe in sand like that of the third test, and in sand and gravel, but on clay, with a base of the same area, there have been cases of complete failure, just as the tests indicate as probable, the column with the pier attached swinging, and being supported only by the adjacent columns, as before stated. The static load carried by each column is about 150 000 lbs., including the weight of the cars in the train, not taking into consideration the disturbing elements caused by the impact of rapidly running trains and of the tremor produced by the action of the brakes, the effect of which is difficult to estimate, but evidently of very much importance. The last two causes are the main sources of failure, as the vibrations from the structure are transmitted by means of the column to the pier and whatever movement reaches the clay upon which the pier rests very quickly affects its bearing qualities, for in its saturated state it becomes a semi-fluid very quickly. That this is due largely to impact seems apparent when it is stated that failure first manifests itself between stations where the speed is greatest. The writer thinks this kind of foundation should not be trusted beyond 10 lbs. per square inch under the existing conditions, and even then the

pier should be massive enough to take up the tremor largely by its inertia. If the pier is too light for this, the interposition of 2 or 3 ft. of broken stone between the base of the pier and the clay might be effective and economical. Mr. Rowe.

J. A. L. Waddell, M. Am. Soc. C. E.—*Medium Steel versus Soft Steel.*—A comparison of opinion on this subject expressed in the discussion shows quite a diversity of ideas, with the preponderance in favor of medium steel. Those who advocate the use of soft steel do so because of one or both of two claims, viz., first, when soft steel is adopted, reaming may be dispensed with; and, second, soft steel is safer than medium steel on account of its greater uniformity and less liability to crack. These claims do not hold, for the reaming of every quality of steel or wrought iron is necessary, not only to remove the injured material, but also to ensure proper matching of rivet holes, and the greater uniformity of soft steel as compared with first-class medium steel is problematical. It seems from the discussions that there should be a slight difference in the ultimate strength of acid and basic steel, as suggested in the paper. Mr. Treadwell strikes the keynote to this question when he points out that the limits of soft and medium steel overlap to such an extent that manufacturers often make the same quality of metal answer for both classes, and when he suggests a compromise in the classification to suit the various manufacturers of structural steel. For such a compromise the author would suggest the following: Soft steel, 50 000 to 58 000 lbs.; medium steel, 58 000 to 66 000 lbs.; high steel, 66 000 to 74 000 lbs. Mr. Waddell.

With this classification soft steel should be used for rivets and adjustable members only, medium steel for all other portions of all viaducts, elevated railroads, bridges of ordinary span lengths, and the floor systems and lateral systems of long-span bridges, and high steel for the main truss members and pins of long-span bridges.

It is evident that basic open-hearth steel has come to stay, and that it will be used ordinarily in preference to acid open-hearth steel on account of its slightly lower cost. It appears also that the best results are not attained with the basic product by demanding an average ultimate strength as high as 64 000 lbs.; consequently, the proper thing to do is to lower the ultimate requirement to suit the manufacturers of basic steel. From the author's experience during the last three years, he would consider that a range in ultimate strength from 58 000 to 66 000 lbs. would suit very well for basic open-hearth steel as at present manufactured. The soft steel, of course, would also be manufactured by the basic open-hearth process, but the high steel should preferably be made by the acid open-hearth process.

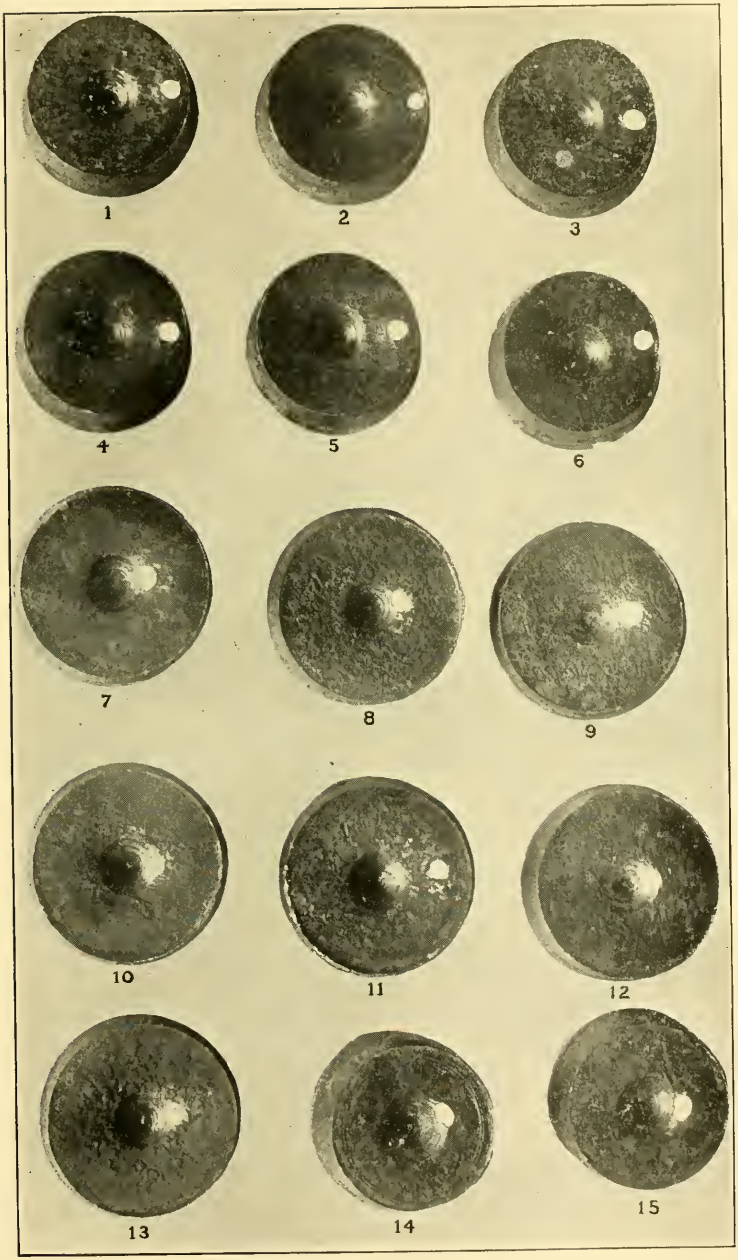
Sub-Punching and Reaming.—A comparison of the opinions on this subject expressed in the discussion shows considerable diversity, with the preponderance in favor thereof. Some claim that accurate work

Mr. Waddell. and properly matched rivet holes are attainable without sub-punching. Such has, unfortunately, not been the author's experience hitherto, for he has had a great deal of trouble from badly matching holes in the field whenever the sub-punching was not called for.

Anticipating claims in the discussion that rivet holes will match properly without sub-punching, the author a short time ago requested his chief inspector to procure for him from a certain prominent bridge shop, where some of his work was then being manufactured, a couple of dozen specimens of punchings showing by the template center marks variations from correct location. Plate XI is engraved from a natural scale photograph of fifteen of these punchings, the proper centers being indicated by the white spots, which were marked on the punchings by rubbing chalk into the template center holes.

The showing made by these specimens is most discouraging to those who hope to obtain good shop work, either by simple punching or by sub-punching and reaming. It took the inspector only about a minute apiece to find these eccentric specimens, which shows that badly matched holes at this shop are by no means uncommon, and confirms the author's opinion formed by previous experience with work from the same shop. The cause of such great eccentricity is certainly the objectionable piece-work system mentioned in Mr. Stowell's discussion. In the author's opinion, piece-work in bridge shops should be discouraged in specifications for structural steel-work. Fortunately, though, such a bad showing as that given on Plate XI would not be made by more than one or two of the large bridge manufactories, although Mr. Horton says in his discussion that $\frac{1}{8}$-in. eccentricities in punched work are of common occurrence. The author's experience with two of the manufacturing companies on the Union Loop and Northwestern Elevated lines leads him to the conclusion that punching can be done with a general limiting variation of $\frac{1}{16}$ in. To illustrate the effects of variations of $\frac{1}{16}$ and $\frac{1}{8}$ in. for both sub-punching and full-size punching, the author has prepared the drawings shown in Fig. 38. They give the worst possible combinations of eccentric holes for two, three and four pieces of metal connected by $\frac{7}{8}$-in. rivets. It is evident from these diagrams that if the limit of $\frac{1}{16}$-in. variation be adhered to, and if the work be sub-punched and reamed, there will be no irregular holes to fill by the rivets. If the holes be punched full size, the resultant holes will often be quite irregular and probably often not completely filled. If the limit of $\frac{1}{8}$ in. be permitted, the reaming will make the holes nearly true circles, and small enough to be completely filled by the rivets, but when the holes are punched full size, the irregularity will often be so great that the rivets cannot fill the holes.

In the author's opinion, inspectors ought to hold down the shops to a general limit of variation in punching of $\frac{1}{16}$ in., passing occa-


1
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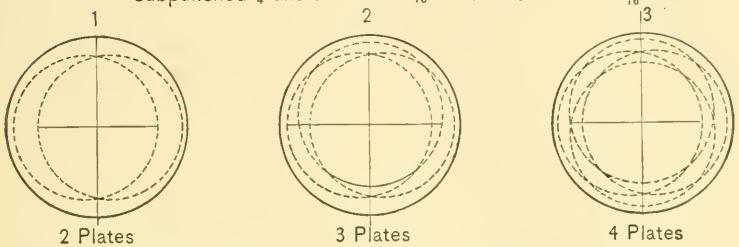
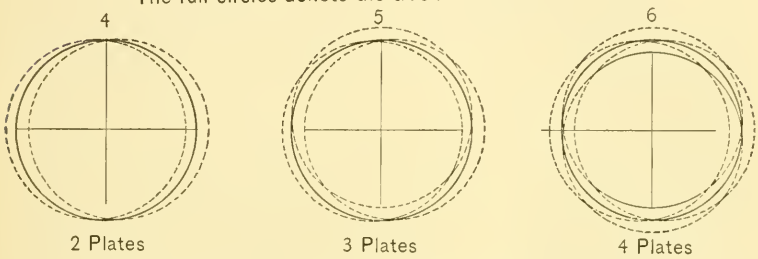
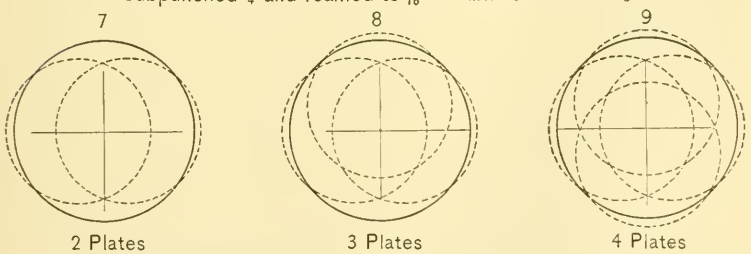
Subpunched $\frac{3}{4}''$ and reamed to $\frac{15}{16}''$ Variation of holes $\frac{1}{16}''$



Punched full size but not reamed. Variation of holes $\frac{1}{16}''$
The full circles denote the true location of the holes.



Subpunched $\frac{3}{4}''$ and reamed to $\frac{15}{16}''$ Variation of holes $\frac{1}{8}''$



Punched full size but not reamed. Variation of holes $\frac{1}{8}''$
The full circles denote the true location of the holes.

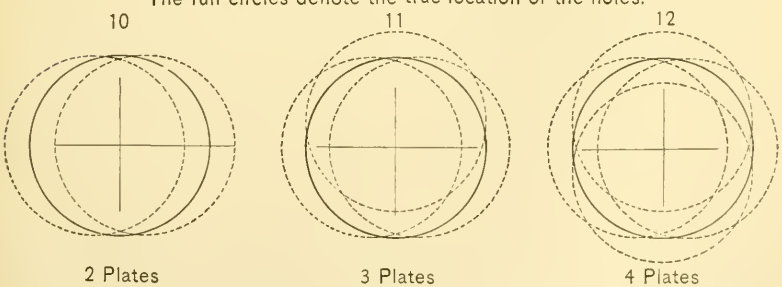


FIG. 38.

Mr. Waddell. sionally a few variations between $\frac{1}{16}$ and $\frac{1}{8}$ in., and rejecting any piece where there is a variation exceeding $\frac{1}{8}$ in.

Some one may remark that, if such variations as those just mentioned be permitted, the metal injured by the process of punching will not all be removed by the reaming; but it must be remembered that it is only an occasional hole in good shop work that will vary as much as $\frac{1}{2}$ in. from correct location, that not more than one-fourth of the holes will vary over $\frac{1}{16}$ in., and that most of the combinations of eccentricities shown in Fig. 38 will be, to say the least, unusual.

The author's experience on the Chicago elevated railroads has confirmed him, as the same experience has convinced Mr. Weston, the chief engineer, in the opinion that, except solid drilling, which as yet is too expensive, "reaming is the only method which will ensure an exact coincidence of the rivet holes in the component pieces of the various members of the structure"; and there has been nothing said in the discussion which even tends to shake the author's conviction on this subject.

Cement and Concrete.—Answering Mr. Hall's question concerning fineness, the author would state that there was no intention of excluding foreign Portland cements by specifying that 90% should pass the No. 100 sieve. In fact, there was a considerable amount of a foreign cement used at one time on the work; this was an extremely fine-ground cement and a very superior article, if not too old or damaged when used.

It has been the author's practice up to the present time to specify both superior and inferior limits for the tensile strength of cements owing to a notion, which formerly prevailed, that a cement which develops its strength slowly is much more likely to retain it than one which develops it very quickly. The author must confess that he is still prejudiced this way, but acknowledges readily that he may be wrong in the case of Portland cements. In case of the natural cements, though, he feels confident that this notion is about right.

For field practice, the author does not specify the temperatures of the air and water, as these cannot always be regulated conveniently, but for laboratory tests he would do so.

Answering Mr. Stuart's remark about the wide latitude allowed for tensile strength, the author would reply that his specifications are so drawn as not to exclude any really good cement because of a tendency to slow setting, and, again, the results of briquette tests depend greatly upon the personal equation of the man who made the briquettes.

Answering Mr. Belknap's remark, that a one-three-six mixture of concrete will have all the voids in the stone filled, the author would reply that such would in all probability be the case, were the concrete always thoroughly mixed, but his experience proves that such a

mixture often shows numerous voids. On this account, as stated in the paper, he prefers to use for bridge piers a one-three-five mixture for concrete deposited in the air, and a one-two-four mixture for concrete deposited under water. Mr. Waddell.

The author certainly never intended to recommend an "eminently slow-setting cement" for concrete to be deposited under water. Mr. Belknap does not recognize the fact that none of the cement for the Chicago elevated railroads was to be used in that way.

Paint.—It is to be regretted that the paper has brought out so little discussion concerning the painting of metalwork. However, Mr. Rowe's investigations are valuable as far as they go, but they are unfinished.

It is often amusing to hear the conflicting opinions of even well-informed engineers concerning the paint question. Some say that the oil is everything and that any kind of a pigment will do, while others say that the pigment is the sole protective agent and the oil only a solvent. Some condemn *in toto* the use of thinners, while others say that they improve the paint and add to its life. Some say that red lead is the only proper paint to use, while others claim that it is inferior to iron oxide paints. Some think that the last-named pigments make the best possible paints, while others say that they are merely iron rust, and that their use is simply an invitation for rust to develop. Some say that patent mixtures and secret process paints are all humbug, while others pin their faith to some especial mixture or mixtures, or to some real or fancied manipulation of known or unknown ingredients. In short, the engineering profession is all at sea on the paint question, and is likely to remain there until some organized investigation is made. In the author's opinion, the subject is one of sufficient importance to warrant the appointment of a special committee of the Society to experiment and investigate on the subject for a term of several years until valid conclusions can be reached.

The author's idea of coating the metal with oil before it leaves the shelter of the roof of the rolling mill is to prevent rust from forming while the metal is in transit to the shops or stored outside of the latter waiting to be manufactured. This method would certainly give the mill people some extra trouble, but that could be paid for. It is claimed, and perhaps justly, that the greasy surface of the oiled metal gives trouble in laying off the work in the shops, and that on this account a coat of carbon primer at the mills is preferable.

The author's preference for Eureka paint was due primarily to the high recommendation given it by A. P. Boller, M. Am. Soc. C. E., and afterwards to the results of Mr. Rowe's preliminary experiments. Mr. Rowe found, however, several other paints that stood his tests as well as did the Eureka.

One objection to a coat of oil alone at the shops after manufacture

Mr. Waddell. is that when the metal is shipped, there is often no certainty as to how soon it will receive its first coat of paint. The author has often noticed metalwork badly rusted because it was only oiled at the shops and because its erection was delayed. The shipping of metalwork covered with undried paint, as mentioned by Mr. Boller, is a very reprehensible practice, and should be prohibited in standard specifications for structural metalwork.

The great uncertainty on the paint question is due to a number of causes, the principal of which are the following :

Permitting rust to form on the metal before the first coat of paint is applied.

Applying the first coat improperly, covering metal from which mud, ice, grease, etc., have not been removed.

Adopting cheap paints from false notions of economy.

Dishonest practices on the part of the manufacturer or mixer of the paint.

Carelessness in mixing paint, and neglecting to keep heavy paints properly stirred.

Slovenliness in applying the paint to the metal.

Using paint that has stood in pots over night and has deteriorated thereby.

Neglecting too long to repaint, and thus allowing rusting to set in.

The requisites for an ideal metal paint are the following :

Thinness, so that it can be applied readily, and so that it will cover a comparatively large surface per gallon.

Lightness of the solid particles, so that there will be no settlement in the bottom of the paint pot.

Great and close adhesiveness to the metal.

Quickness in drying.

Absence of blisters in both fresh and old painted surfaces.

Ability to receive well and retain closely one or more additional coats of paints of the same kind or of other kinds.

Durability.

Cheapness in first cost.

The man who will invent a paint that will fill all eight of these requirements, and who can demonstrate to engineers that he has done so, can certainly make a fortune out of his invention.

Four-Column versus Two-Column Structures.—Several engineers appear to disagree with the author in his preference for the four-column structure. He was influenced in his decision principally by the following reasons :

The cantilevering of an entire track beyond a column is rather awkward construction and causes reversing stresses in the cross-girder.

The thrust from braked trains can be more readily taken care of with four columns than it can with two. Mr. Waddell.

The four-column structure will prove more rigid than the two-column structure.

Mr. Pratt's objection to the four-column structure on account of the possibility of the settlement of foundations is not a valid one, for properly designed and built foundations will never settle. If a single settlement of a pedestal on either of the author's Chicago lines of elevated railroad ever occurs, it will be a matter of great surprise to him, although he is not responsible for the sizes of the concrete pedestals, as Mr. Weston varied them to suit the different conditions as they developed. However, Mr. Weston has always tried to err upon the side of safety on this question of foundations, owing to the expensive experience he has had in repairing the faulty work on the old portion of the Lake Street Elevated, which was built before he was chief engineer.

Mr. Pratt's unfortunate experience with pedestal foundations may be due to a softer stratum of material underlying the gravel, or perhaps to the fact that it is within the realms of possibility to double the pressure on one side of a pedestal foundation by the thrust of a braked train.

As the author has designed the metalwork on the Northwestern Elevated, a settlement of one pedestal in a bent would be less injurious to it in the case of the four-column structure than it would be in the case of the two-column structure.

Mr. Gates' objection to the four-column structure, because of obstruction to traffic, will not hold, as this class of construction is used only on the company's private property, where no traffic exists.

Braced Towers versus Solitary Columns.—The author's braced tower design appears to have met with general approval from those discussing the paper, although Mr. Smith dissents therefrom, stating that the thrust from braked trains "is not conveyed, to any extent, to the columns," and that "no bending can be produced upon the columns, for it is counteracted by the deck."

These statements are certainly incorrect, for no one will deny that there is a great thrust exerted by stopping in the shortest possible distance, with the air brakes, a train moving at a velocity of 40 miles per hour, and that this thrust must eventually reach the ground. If there be longitudinal sway bracing like that adopted for the Northwestern Elevated, the thrust will travel by that; but, if not, it must go by way of the columns and produce bending thereon.

It is true that the continuity of the deck tends to distribute this thrust over a number of columns, but the extent to which this distribution takes place is a matter of surmise. Some engineers appear to forget that when a light column carrying a vertical load is deflected

Mr. Waddell. from the vertical by a thrust, it is subjected to two bending moments, viz., that due to the thrust itself and that due to the vertical load, the lever arm for which is the total deflection. The column has therefore to withstand the combination of these two moments and the vertical load. Mr. Smith says that the thrust upon one track is distributed over the other three. He forgets that two trains on contiguous tracks will often approach a station at the same instant, running in the same direction, with the brakes set. If at the same time there be a train or two trains starting on the other tracks, all three or four thrusts will be in the same direction. Mr. Smith talks of setting the structure in motion before any bending of columns can occur. He would reduce the question to one of dynamics, while it is, upon the face of it, simply one of statics. He says:

"Were it possible to design a column section in any case which would carry the load due to compression, without longitudinal strength, then some metal might, in this case, be necessary to withstand any light stress caused by thrust. This being impossible, however, the conclusion is drawn that any metal used in any part of a structure to withstand horizontal thrust in a longitudinal direction is superfluous and needless expense."

This is a bold statement by Mr. Smith, and probably he is the first to express it so plainly, although some such erroneous notion must have existed in the minds of the designers of most of the older elevated railroads.

Mr. Campbell's experience on the Sioux City Elevated, where the effects of both longitudinal and transverse thrusts on the columns were entirely ignored, is pretty conclusive as to the necessity of giving due consideration to horizontal loads. As Mr. Campbell states, the vibration of the structure "was plainly noticeable at a point 2 000 ft. away from the moving train." The author has been told that during erection long portions of this structure moved as much as 2 ins. longitudinally and had to be moved back by jack-screws. In this work the columns were proportioned for the effects of live and dead loads only, as Mr. Smith would advise.

To illustrate the necessity for taking care of longitudinal thrust and traction of trains, the author herewith reproduces extracts from a letter concerning the paper from H. G. Kelley, M. Am. Soc. C. E.:

"Many of the points involved are of special importance, and if accepted as correct will require a radical departure on certain lines from the present methods of design:

"The point to which my attention has been especially directed by reading your paper is the resultant of the traction force exerted by engines, and the effect of such resultant upon structures, due to the passage of engines and trains. The mathematical principles involved will no doubt be brought forth in the published discussions, and while your assumption that 20% of the greatest live load between two adjacent expansion points will act as a horizontal thrust may not be entirely agreed to, nevertheless experience has shown that a consider-

able allowance should be made and provided for; therefore any facts obtained by actual experience in construction and maintenance will assist materially in arriving at a true conclusion, and in this consideration wooden trestle-work, which constitutes a large portion of the bridging of this country, should not be excluded, for it presents valuable information concerning structures in which theoretical considerations are usually excluded, and details to take up or reduce longitudinal vibrations are seldom constructed. Mr. Waddell.

"I will therefore present one case coming under my own observation, and in fact under my charge, which is an especially valuable one, showing, as it does, that a longitudinal vibration is transmitted through

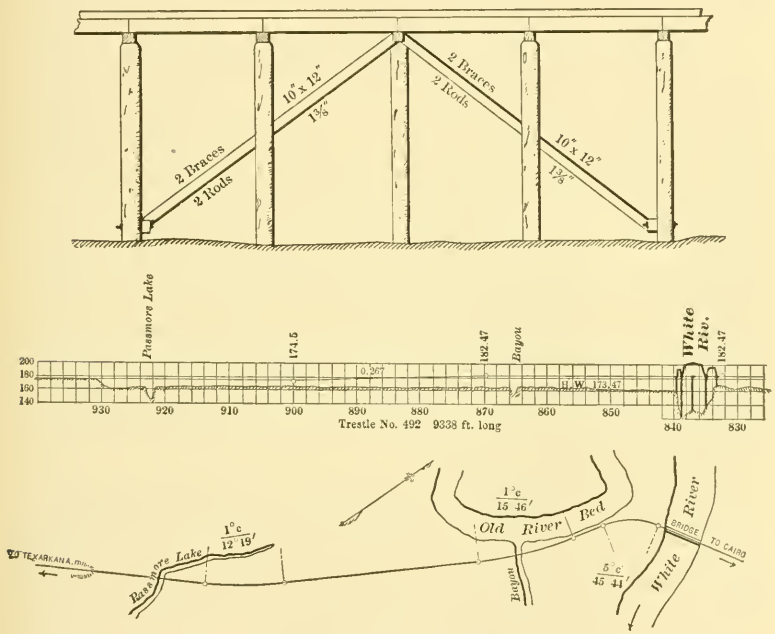


FIG. 39.

elevated structures for surprising distances. The structure is a wooden trestle, upon the line of the St. Louis Southwestern Railway. This trestle was constructed of pile bents, with panels of 13 ft. 8 ins.; each bent contained four piles, except in the deepest portions, where five piles were used to the bent; the piling was of oak and red cypress, with specifications calling for not less than 10 ins. of heart at the point; the deck was composed as follows:

"Caps.....	12	x	12	ins.,	12 ft. long.
"Stringers....	6	x	14	"	14 " long, 3 ply on each side.
"Ties	6	x	8	"	9 " long, with 12 ties to the panel.
"Guard rails..	6	x	8	"	16 " long, notched down 1 in. over the ties, and bolted to every fourth tie.

Mr. Waddell. "Every cap was drift-bolted to each pile under it, and each chord of stringers was drift-bolted to the caps.

"Upon examination of the drawing (Fig. 39), which I enclose, you will note that the trestle varies from 10 to 30 ft. in height, and has a total unbroken length of 9 338 ft., with three curves in its length.

"Upon assuming charge of the bridge department of the above-mentioned road several years ago, it became necessary to make a personal examination of the various structures, and I have selected the case of trestle 492 as one out of several trestles of unusual length where the same results were noticed. My first inspection of this trestle showed a visible longitudinal variation of such extent, under the passage of trains, that a careful investigation was made to determine the extent and force of the thrust.

"To make the following facts perfectly clear, reference should be made to the accompanying drawing (Fig. 39). From this you will notice that at its north end the trestle connects with a bridge across the White River. This bridge at the time of the observation consisted of an iron draw span of 355 ft., and two combination Pratt trusses of 125 ft. each, one span being at each end of the draw-span; both of these combination spans were upon falsework. The observations disclosed that, when any north-bound train, even at a speed of but 12 miles an hour, rolled upon the trestle at its extreme south end, a longitudinal vibration was transmitted in a few seconds to the north end of the trestle, and by the time the train would reach the tangent, at station 902, the vibration at the span reached a maximum of 1½ ins., this impulse being conducted to the span itself and vibrating it in unison with the trestle, the measurements being taken at the point where the rails of the fixed span rested upon the end floor beam rail rests of the draw span. The construction of the trestle precluded the opinion that the vibration was confined to the deck alone, for the drift bolting to the caps made it certain that a portion of the thrust was communicated through the piling to the ground, causing the piling to act as beams as well as posts.

"I at once had constructed a system of struts to take up or reduce the thrust, the general plan of which is shown on the drawing (Fig. 39). It consisted of two yellow pine beams, 10 x 12 ins. in cross-section, running from the cap on one bent to a brace timber at the foot of the piling on the second bent each way from the first one; and in addition to this, iron tension rods, 1¾ ins. in diameter, were placed beside each strut and brought into tension with turnbuckles.

"This system of strutting was constructed at two points in the trestle, and practically takes up all vibration, but under the influence of a heavy freight train I have see these strut timbers buckle from ¼ to ⅜ in. out of line in the direction of their least dimension.

"The necessity for this strutting has become so apparent that I provide for it on other important trestles of extreme length by using a modification of the original plan."

Had Mr. Kelley tried the experiment of bringing the train to rest suddenly on the trestle with the air brakes, he might have found a vibration even greater than the 1½ ins. observed, although this is large enough. Mr. Kelley's remark about the buckling of his longitudinal timber struts from the longitudinal thrusts of heavy trains ought to be sufficient to convince even the most skeptical that such thrusts do exist and that they are carried down to the ground by the columns.

Mr. Parsons' transit observations on one of the New York elevated railroads gives additional evidence of the effects of thrust from braked trains. Mr. Waddell.

How any one can deny that large vibrations are injurious to metal-work, it is difficult to conceive; for, as before stated, they put a double bending moment on the columns, and tend to work loose the rivets that connect the deck thereto.

Mr. Nichols and two or three other engineers question the author's assumption of 20% as the coefficient of friction for the thrust of a braked train. Trautwine places it as high as 25%, while Messrs. Cooper, Schneider and other writers of standard specifications make it 20 per cent. As for the distribution of the thrust, the rails and guards on tangents certainly tend to distribute it over some distance, especially when the track is new; but, on sharp curves and with old track, it would not be proper to place much reliance upon such distribution. Moreover, why divide up the thrust, when assuming it concentrated produces such beneficial results to the whole structure by increasing its rigidity ? When the columns are fixed at both top and bottom, as is the case on all of the author's Chicago work, the lever arm of the thrust is only one-half of the unsupported length of the column, consequently the bending moment and the section of column derived therefrom are by no means excessive. This is shown by the comparatively small weights of metal of the author's designs, as given on page 349, viz., 391 lbs. per lineal foot per track for a four-track structure on private property, 385 lbs. per foot per track for a double-track structure on same, 485 lbs. per foot per track for a double-track structure spanning a double-track cable railway in streets, and 571 lbs. per foot per track for a double-track structure in streets spanning from curb to curb with 41 ft. between centers of columns. It is true that these figures are for the comparatively light live load assumed for the Northwestern Elevated, but the assumption of a heavier live load would affect little else than the sections of flanges of longitudinal girders, and in street lines those of cross-girders also.

From the tables in Mr. Nichols' paper* entitled "The Brooklyn Elevated Railway," the author has compiled the following weights of metal per lineal foot of double-track structure, omitting the weights of station metal and not considering the "Old Brooklyn Line." For columns on curbs the weights run from 1 095 lbs. for a 32-ft spacing up to 1 469 lbs. for a 45½-ft. spacing, and for columns in the street 1 195 lbs. The corresponding weights for the Chicago Union Loop are 1 375 lbs. for a spacing of 41 ft., and 1 150 lbs. for columns in the street. If an interpolation for a 41-ft. spacing is made in Mr. Nichols' weights, 1 344 lbs. will be found ; and, averaging this with the weight of structure for columns in street, 1 270 lbs. is obtained, as against 1 263 lbs.,

* *Proceedings*, Institution of Civil Engineers, Vol. cxxvii, p. 333.

Mr. Waddell. the corresponding average for the Union Loop, showing that the author's Chicago structure is a little lighter than the average for corresponding lines in Brooklyn, in spite of the fact that the author's live load is on an average for all parts of the structure 17½% greater than that used in designing the Brooklyn lines, as indicated in Mr. Nichol's paper. With such a showing as this, the author cannot be justly accused of extravagance in his designs because he proportioned his columns for the effects of thrust from braked trains and endeavored throughout his entire designs to conform in every particular with the principles of design enumerated in his paper.

If anyone doubts the advantages of putting a little extra metal into the columns and fixing them at both top and bottom, let him stand for a while on one of the platforms of the Union Elevated Loop of Chicago and note the vibration, then try the same experiment on a number of the elevated railroads of New York and Brooklyn, and compare the results. He would probably be considerably surprised; for he would find hardly a tremor on the Chicago road, while on some of the Eastern roads the vibration would be so great as to prevent him from writing legibly in a note-book.

Wooden Floor.—Replying to the comments of Mr. Nichols and others on the wooden floor system adopted, the author would state that it was based upon the results of the experience of those who have been operating elevated railroads for many years. Whether both inner and outer guards are requisite is certainly problematical. In railroad bridges the author relies on the inner guards to keep derailed wheels from receding far from the rails, and on the outer guards to space the ties and keep them from bunching.

Mr. Weston has made two or three improvements on the original design for the floor system, notably the use of tie-plates.

Replying to Mr. Stuart's remark concerning the use of short hook bolts, they were necessitated by the 5-ft. spacing of the longitudinal girders.

Mr. Pegram's design for a floor without cross-ties, as adopted for the Kansas City Elevated Railroad, has one very serious fault, viz., that the trough will collect snow and sleet, which in a cold climate would be liable to freeze to such an extent as to stop traffic altogether.

The author cannot agree with Mr. Tomlinson's view that an 18-in. spacing for 6 x 8-in. ties is an improvement on a 14-in. spacing, for the reason that a derailed wheel has a pretty deep hole to drop into when the open space between ties is 10 ins. wide, and that the bumping which would result from climbing over the ties and dropping between them would be liable to cause disaster. Fig. 40 shows relative conditions that would exist with a 30-in. derailed wheel, assuming that the flanges cut into the ties ½ in. at the corners.

Mr. Waddell.

Answering Mr. Belknap's charge expressed thus, "it is difficult to conceive that a railroad company would countenance the gross extravagance of using the most costly grade of timber when the preservative treatment of cheaper grades would give an article much more economical," the author would reply that, in asking for bids on timber, two specifications were used, the first being the author's calling for clear heart timber, and the second that of the Manhattan Elevated Railroad Company allowing a certain amount of sap wood on the corners. The difference in the lowest bid on the two specifications amounted to about 50 cents per thousand, so the president of the railroad company himself decided to adopt the heart timber. In spite of what Mr. Tomlinson says to the contrary, the author thinks that this was a wise decision, for it is the sap wood, both treated and untreated, that fails first.

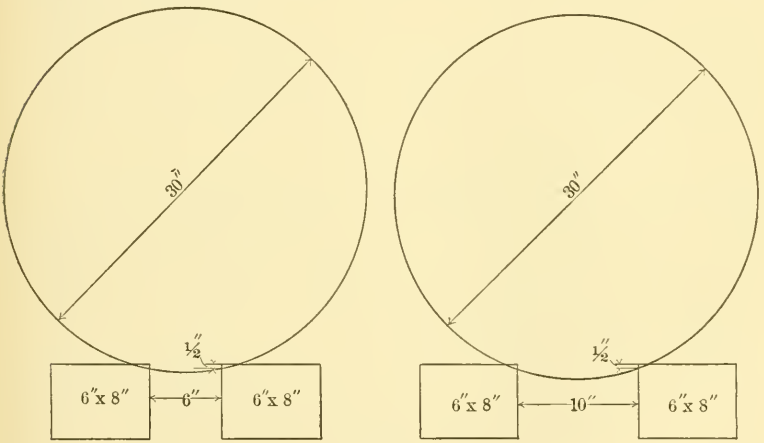


FIG. 40.

Data Concerning Existing Elevated Railroads.—It is possible that the author has, much to his regret, given offence to certain engineers by his sweeping assertion that "the results of his investigation, as far as the designing of the metalwork is concerned, amount simply to the accumulation of a great mass of information exemplifying 'how not to do it.'" Such was certainly not his intention, although the statement was made with due intent and to accomplish an important object. Moreover, later and more extended examinations of existing structures confirm him in his opinion.

The *raison d'être* for his statement is that, when both the Wabash Avenue Extension of the Lake Street Elevated and the Northwestern Elevated contracts were about to be let, the strongest kind of pressure was brought to bear upon the president of these companies to induce him to set aside the author's plans and specifications and to adopt

Mr. Waddell. others submitted by bidders on the plea that the latter were the same as those used for the New York and Brooklyn elevated railroads, which roads represented practically the *ne plus ultra* of both design and manufacture. It was with great difficulty that the author overcame this opposition; but, thanks to the sound business policy of the president, he was finally successful in having both his plans and his specifications adopted and adhered to. Were it not for this stand which he then took, the unscientifically designed and crudely manufactured structures of the New York and Brooklyn elevated railroads would still be the criterion of excellence for that class of construction, notwithstanding the fact that the Metropolitan Elevated of Chicago, then in course of construction, is in most particulars greatly their superior.

The true reason why elevated railroads have been so unscientifically designed in the past is that, as a rule, the designing has been left almost exclusively to the manufacturing companies, which, being more interested in profits than in anything else, naturally detailed the metalwork so as to have it go through the shops quickly and erect readily; and all considerations of scientific design appear to have been ignored because of these requirements.

The intent, therefore, of the author's "sweeping assertion" is to establish for all future elevated-railroad work a precedent for taking the designing and the preparation of the specifications entirely out of the hands of the manufacturer of structural metalwork and placing them where they belong, viz., in the hands of the consulting engineer and expert in such construction. Whether the attempt will prove successful or not, remains to be seen.

Thanks to the courtesy of Mr. Clarke, in forwarding an advance copy of his discussion, the author was convinced of the necessity of having a thorough examination of all the New York and Brooklyn elevated railroads made by a competent engineer, in order to enable him to answer properly, not only Mr. Clarke's discussion, but also those of like tenor, the writers of which take exception to the author's "sweeping assertion." It was therefore decided that the author's chief office assistant, Ira G. Hedrick, Assoc. M. Am. Soc. C. E., should proceed east to make the necessary examination and report. Following are extracts from his letter of instructions:

"You will please proceed to New York at your earliest convenience and examine thoroughly all the elevated railroads of both New York and Brooklyn, with a view to ascertaining whether they show any signs of incipient failure, and, if so, what such failures consist of and the causes thereof. After your examination is finished, you will please make me a full and elaborate report of the results of your investigations. In this report I desire you to point out all departures in detailing from the requirements of good construction as outlined in my paper on elevated railroads, and indicate the evil effects of such departures, if there be any. You will, when in New York, call on the Secretary of the American Society of Civil Engineers and obtain from

him copies of all the discussions of my paper, so as to include in your investigations a study of all points concerning existing elevated railroads that are raised in said discussions. In reporting to me you will please answer all such points, so that I can incorporate your report in my *résumé*, and thus let you reply for me to the statements made in the discussions." Mr. Waddell.

In accordance with these instructions Mr. Hedrick spent a couple of weeks in New York and Brooklyn making his investigations, and after his return presented a report from which the following extracts are made:

"Referring to the discussion of O. F. Nichols, M. Am. Soc. C. E., the writer is of the opinion that in most instances in the New York and Brooklyn lines the connections of columns to foundations are strong enough to take care of all stresses that ever come upon them. Plenty of anchor bolts are used, and these are carried well down into the foundations, and the cast-iron bases grip the feet of columns firmly, so long as the cement or filling used between the column and casting is well preserved. Where columns are placed in the roadway, cast-iron bases, such as are used for the Second Avenue line in New York, or for the Kings County Elevated in Brooklyn, are probably as satisfactory and economical as any that can be used. But where columns are on curbs, or on private property, the column foot shown on Fig. 5, which was used on the Northwestern Elevated Railway, is equally as good and certainly much more economical."

"Where the bases are made of structural steel, no lugs are used on the columns, but the anchor bolts merely pass through the base plate and angles connecting the column to the base plate. Four anchor bolts are used for each column, and they are placed very near the corners of the base plates; therefore the strength and rigidity of the connection between the column and the pedestal depend entirely on the ability of the corners of the base plate and angle to resist bending. This style of base is certainly not so strong as where the anchor bolts pass through bent plate lugs which are firmly riveted to the feet of columns, as is done in the detail used for column bases on the Northwestern and Union Loop Elevated Railways in Chicago.

"In regard to the actual amount of longitudinal thrust load from braked trains, and the distribution of this load over the structure, there seems to be considerable difference in opinion among engineers, and Mr. Nichols takes a very decided stand against the assumptions used in designing the Northwestern and Union Loop Elevated Railways.

"While it is no doubt true that the assumption that 20% of the greatest live load between two expansion joints acts as a horizontal thrust upon the columns between same is on the side of safety, yet it is a fact that light columns and weak connections between columns and cross-girders are probably the causes of more vibration in the existing elevated structures in New York and Brooklyn than are all the other objectionable features combined. On all of these structures, excepting in one or two instances, a very perceptible longitudinal vibration can be felt when the brakes are applied to a train, and in the taller portions of the Second and Eighth Avenue lines these vibrations seem to have an amplitude of from one-half inch to an inch.

"On most of these lines there is an expansion joint in each panel, which arrangement makes each bent act alone in resisting the longi-

Mr. Waddell.

tudinal thrust that may come upon the panel attached thereto, excepting, of course, the aid it may receive through the track system.

"The writer cannot agree with Mr. Nichols in regard to the continuity of track and the consequent distribution of this horizontal thrust or traction load, as all joints in the track rails and guard timbers must adjust themselves for expansion and contraction of the metal superstructure, and consequently the whole structure is practically non-continuous over expansion joints; therefore the most scientific and rational way to design the columns and cross-girders is to proportion them so that each section of structure between expansion joints can take care of itself entirely independent of any other part of the structure.

"On the portion of the Suburban Rapid Transit Line which rests on brick piers there is, as stated by Mr. Nichols, absolutely no vibration, although the longitudinal girder construction is similar to that of other portions of the structure which are supported on steel columns and in which there is considerable vibration, yet not so much as in many of the older lines. This structure on brick piers certainly demonstrates the truth of your column theory in a most impressive way, and shows conclusively that the great cause of vibration in ordinary construction lies in the columns and their details, and the writer is therefore convinced by his observations that metal, properly applied, is never wasted in columns, although the sections may seem heavy.

"On none of the elevated railways in New York and Brooklyn is any attempt made to carry the longitudinal thrust directly into the columns by lateral struts, and consequently there is considerable cross bending on the transverse girders where the columns are placed on the curbs and where the tracks are located near the center of the streets. But this bending does not affect the structure so much where the cross-girders are double and where the columns are in the street and the tracks placed over them. The bad effects of this bending are noticeable on some of the down-town lines, in which there is a slight canting of the cross-girders when the brakes are applied to passing trains, and in some cases the bolts attaching the longitudinal girders to cross-girders have to be frequently replaced.

"By extending the lateral bracing out to columns and thus firmly fixing their tops, as is done on the Union Loop Elevated Railway in Chicago, the bending on cross-girders is entirely avoided and a much more rigid construction is secured, which can best be appreciated by standing on the last-named structure while the brakes are applied to trains. The writer regrets that he could not take vibration curves on the various structures he inspected so as to give a more definite idea of their relative rigidities, and prove conclusively the superiority of the well-braced structure.

"The writer agrees with Mr. Nichols in regard to the spacing of expansion pockets, and the greater rigidity of the structures in which they are spaced from 150 to 250 ft. apart is very noticeable. The limiting distance for spacing expansion pockets depends upon the stresses produced in columns by the expansion and contraction of longitudinal girders due to changes in temperature. The more rigid the columns, the greater will be the temperature stress for any given distance between expansion pockets, and *vice versa*. For the Union Loop the limiting distance was found to be 150 ft., but on the Suburban Rapid Transit Line, with expansion pockets 250 ft. apart, the metal in columns is probably not strained any higher by temperature stresses than that in Union Loop columns, on account of the much less rigid column section used on the Suburban Rapid Transit Line.

Mr. Waddell.

"In regard to column sections, there is certainly a great diversity of opinion among engineers, as is evident by the many different styles used on the lines in New York and Brooklyn, and it is certainly a difficult task to design a column which is satisfactory in every respect. The Phœnix column and a column made of two channels laced together are used on the New York and Brooklyn elevated roads more than are any of the other styles. There are objections to both of these columns. The Phœnix column is inaccessible for paint on the inside, and consequently its interior is subjected to the unmolested ravages of rust. It may be claimed that no moisture can get inside the column, and therefore that there is no necessity for the application of paint; but that an abundance of moisture and water finds its way to the inside of these columns is proved by the fact that during the winter season these columns are often burst open by the freezing of the accumulated moisture inside. The possible occurrence of such a result makes another serious objection to the Phœnix column.

"The two-channel column with double-riveted lacing is certainly the most satisfactory column used on any of the elevated railways in New York or Brooklyn, but in most instances its efficiency is largely destroyed by cutting the column off below the bottom of the cross-girder. The Fifth Avenue Line in Brooklyn and the Third Avenue Line in New York furnish examples of this defective style of construction, and will be considered later on in this report. The columns built of two channels laced together usually have the webs of channels placed parallel to the center line of structure, so that the webs of channels carry the shear from longitudinal thrust, and the lacing carries the shear from transverse loads. The double-riveted lacing is surely ample to carry the transverse loads due to wind, but on curves the centrifugal load could be much more satisfactorily carried by solid webs, as there is in all cases considerable vibration from trains passing around curves. Two 15-in. channels with webs turned parallel to center line of structure do not give nearly as strong a section longitudinally as two channels and one I-beam, the section used on the Union Loop of Chicago. This I-beam column is just as satisfactory, as far as proper connections are concerned, as the two channel column, and is certainly much more rigid in both transverse and longitudinal planes.

"The investigations made by the writer verify your assertion that all columns should be extended up to tops of cross-girders, which should be solidly riveted into them.

"The assertion by Mr. Nichols that the later structures in New York have the tops of columns so firmly fixed that the structures could be slid bodily over the ice without the columns collapsing would, in the writer's opinion, apply only to the Suburban Rapid Transit Line in New York.

"The straight brackets in use on most of the lines in New York and Brooklyn consist of two small angles with two and three rivet connections to cross-girders and columns, and are almost absolutely useless as bracing. The rivets in these connections work loose, showing that the details are weak and overstrained. A straight bracket with a solid web would be more efficient than a curved bracket, but less pleasing in appearance, but the curved bracket with a solid web is incomparably better than the angle brackets in such common use on the older lines.

"Referring to the discussion by T. C. Clarke, M. Am. Soc. C. E., the writer made a careful examination of the Second Avenue Line

Mr. Waddell. in New York, and in the following pages each of the seventeen essentials of good construction given in your paper are applied to the above-named structure and the evil effects of the violation of these essentials are pointed out.

"*1. Insufficiency of Rivets for Connecting Diagonals to Chords of Open-Webbed Girders.*—The diagonals in the longitudinal girders of the Second Avenue Line are each composed of two angles varying in size from 6 x 4 ins. at ends to 4 x 3 ins. at center. The diagonals are of the single-intersection Warren girder type, and in no case do they intersect on center-of-gravity lines. There are only four or five rivets connecting these diagonals to the chords, and as there are no connection plates in the girders, the rivets connecting the diagonals to the chords are bunched in such a small space that it is hardly probable that the full value of these few rivets is obtained. Some of these rivets are working loose, but not so many as would be expected. Judging from the investigations made, there is probably, on the Second Avenue Line, an average of about twenty loose rivets per mile per month in the diagonals of longitudinal girders. This number is only about one-third as many as are found on the Third Avenue Line, but certainly many more than should be found on a structure which has been properly designed.

"*2. Failure to Intersect Diagonals and Chords of Open-Webbed Girders on Gravity Lines.*—In none of the longitudinal or transverse girders of the Second Avenue Line do the diagonals intersect on gravity lines, while near the ends of these girders where large angles are used these diagonals intersect in some cases as much as 8 ins. off centers.

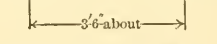
"It will be interesting to take the case of a 45-ft. span (Fig. 41) and figure the combined direct and bending stress on the top chord. The loads assumed for these calculations are the same as were used in designing the Union Loop.

Dead load per lineal foot of track	..	700 lbs.
Live load " " "	..	2 500 "
Total load " " "	..	3 200 lbs., or, 1 600 lbs per lineal foot per stringer.

"Moment at center of girder $= \frac{1}{8} \times 1\,600 \times (45)^2 = 405\,000$ foot-pounds. Effective depth of girder $= 3.25$ ft. Stress $= \frac{405\,000}{3.25} =$ 124 600 lbs.

"Bending on top chord. Let us use the compromise formula $M = 0.1\ Wl$.

Live load, $M = 0.1 \times 11\,000 \times 42 = 46\,200$ inch-pounds.



Dead load $M = \frac{1}{12} \times 350 \times 35 \times 42 =$ 4 290 inch-pounds.

Total bending moment $= 50\,490$ "

Section for top chord, assumed, two 6 x 6-in. 72-lb. angles.

Moment of inertia of top chord $= 45$ net.

$$R = \frac{4.25 \times 50\,490}{45} = 4\,768 \text{ lbs.}$$

$$\text{Direct stress} = \frac{124\,600}{14.4} = 8\,653 \text{ lbs.}$$

"Total extreme fiber stress in center panel of top chord due to combined direct load and bending = 13 421 lbs. per square inch. This is too high an intensity to use where the loads are so frequently applied as they are on this line. The intensity used for the top chord sections on the Union Loop was 9 000 lbs. Mr. Waddell.

"Let us try the end detail of these longitudinal girders. End shear = 22.5 x 1 600 = 36 000 lbs.; eccentricity = 12 ins.; moment due to eccentricity = 36 000 x 12 = 432 000 inch-pounds; moment of inertia of section on $A\ B$ (Fig. 42) = 160 net; $R = \frac{3.5 \times 432\,000}{160} =$ 9 450 lbs., which is all right.

"Let us try an intermediate panel point "X," Figs. 41 and 43. Direct stress in second panel of top chord = $\frac{36\,000 \times 7}{3.25} = 77\,540$ lbs. Therefore $P = \frac{77\,540}{14.4} = 5\,385$ lbs.

P = 5 385 lbs. Stress in diagonal = 15 600 lbs.

Bending from wheels R = 4 768 "

Lever arm for eccentricity = 8 ins.

Moment = 8 x 15 600 = 124 800 inch-pounds.

Bending due to eccentricity R = 11 787 " $R = \frac{4.25 \times 124\,800}{45} = 11\,787$ lbs.

Total extreme fiber stress = 21 940 "

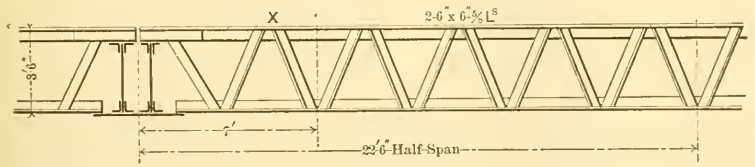


FIG. 41.

"This is too high to strain the top flanges of these girders. From the above figures it will be seen that the eccentric connections are the cause of more stress in the top chords than the combined direct load and bending due to wheel loads. Such unnecessary stresses should certainly not exist in a well-designed structure.

"*4. Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.*—From the figures made for Section 2, it will be seen that the stresses in top chord angles are not excessive for the combined direct load and bending due to wheel loads on top chords, but that the stress due to eccentric connections combined with the two cases named above increases the total intensity to about 100% above what it should be. With proper connections the top chords of this structure would not be overstrained more than 45 per cent.

"*5. Insufficient Bracing on Curves.*—On the Second Avenue Line no bracing is provided on curves, except the ordinary stringer bracing. As a result of this neglect, the stringer bracing connections on curves

Mr. Waddell. are badly overstrained, and the rivets are continually working loose. The bracing frames between adjacent stringers seem to suffer especially from the centrifugal load, and as the diagonals in these frames are of small flat bars, connected by one rivet at each end, and at the intersection at center, they are entirely inadequate for the work they have to do. There is great vibration on all curves caused by passing trains, although their speed is much reduced as they approach the curves.

"On Twenty-third Street, where the line runs from First Avenue to Second Avenue, there is a short tangent between two very sharp curves, and the lack of sufficient bracing is clearly shown by the swaying of the structure in both transverse and longitudinal directions as the trains pass around these curves.

"Rigid bracing frames placed at center of panels would add greatly to the rigidity of the structure. A comparison of the action of this structure with that of the Union Loop Elevated in Chicago under similar loads and conditions would show the great advantage to be derived from a rigid lateral system on curves.

"*6. Insufficient Bracing between Adjacent Longitudinal Girders.*—On the entire Second Avenue line the adjacent longitudinal girders are

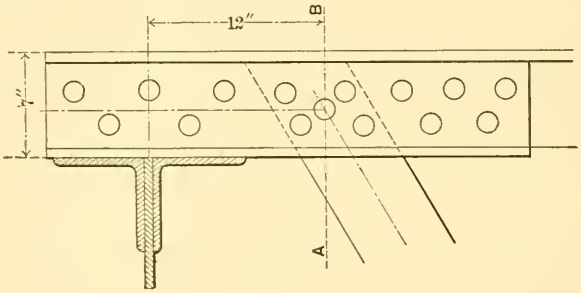


FIG. 42.

braced together with 3 x 3-in. angles in the planes of both top and bottom flanges, with a bracing frame at each end of panel, and one or more at intermediate points according to length of span. As stated before, the diagonals in the bracing frames are of small flats and of very little value as bracing. The bracing angles between the adjacent longitudinal girders are ample to carry all stresses which can come upon them where the structure is on tangent, but as no plates are used for connecting these angles to the longitudinal girders, only two rivets are used to attach them to the girders. These two-rivet connections do not stand the wear and tear of the constant vibration produced by the heavy traffic, and as a result many of these rivets work loose. The single rivets in the bracing frame connections also frequently work loose. Enough metal has been used in the bracing between longitudinal girders to make a thoroughly rigid system if properly distributed. If the bracing angles between bottom flanges of girders had been omitted and the same amount of metal were used in providing suitable connection plates and rigid bracing frames joining the longitudinal girders at the center of panel, and if all connections were made with three or more rivets, the structure would be more rigid and there would be no trouble with loose rivets in the lateral bracing.

"*8. Excess of Expansion Joints.*—In the Second Avenue structure, provision is made for expansion in every panel, and this excess of expansion joints is one great cause for vibration in the structure. Neglecting the continuity of the track, each bent has to take care of all longitudinal thrust from traction or braked trains coming on the panel which is attached to it. There can be no real necessity for the expansion joints on this line being placed closer than at every fourth bent, or, say, from 175 to 200 ft. apart, and such an arrangement would add a great deal to the rigidity of the structure. Mr. Waddell.

"*9. Resting Longitudinal Girders on Top of Cross-Girders Without Riveting Them Effectively Thereto.*—The attachment of longitudinal girders to the gross-girders on the Second Avenue line is the same for both fixed and sliding ends, except that the holes for the bolts used in the connections at sliding ends are slotted and are provided with washers, while for the fixed ends the holes are made to fit the bolts or rivets. The connection of longitudinal girders to the cross-girders is not well designed to transmit the longitudinal thrust from the former to the latter. The bolts connecting the ends of the lower flanges of the longitudinal girders to the cross-girders are missing in a great many instances, especially in portions of the structure on curves.

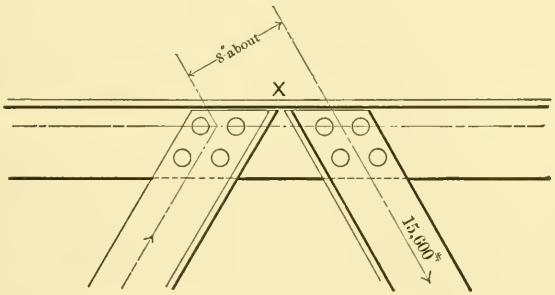


FIG. 43.

"The end details of these longitudinal girders have a great deal to commend them from a manufacturer's point of view, as they are simple, and no special details whatever are required for the sliding ends.

"*10. Cross-Girders Subjected to Horizontal Bending by Thrust of Trains.*—No struts are used on the Second Avenue line in any case to carry the thrust from braked trains to column direct, but the cross-girders are relied upon to carry this load in bending. Throughout the entire line all cross-girders are composed of two separate girders, each of four angles and a solid web plate, or a lattice web system. These girders have stay plates between them at all points where the longitudinal girders connect to the cross-girders, so these heavy cross-girders are probably amply strong to carry all transverse bending that comes upon them in portions of the structure where the columns are located in the street beneath the tracks. But on portions of the structure where the columns are placed on curbs, the bending should be taken care of by means of struts extending out to the columns. On some of the down-town portions of structure with the columns located on curbs, there is a perceptible canting of the cross-girders when the brakes are applied to passing trains, and the writer was told by persons in a position to know that this torsion on the cross-girders is the cause of a great many rivets and bolts working loose.

Mr. Waddell. "*11. Cutting Off Columns Below the Bottom of Cross-Girders and Resting the Latter Thereon.*—The columns on this line are all cut off below the bottoms of cross-girders and are provided with cast-iron caps which are bolted to the tops of columns and to the cross-girders. The cross-girders are double, as previously described, therefore they furnish quite a large bearing area on top of columns. A large plate 1 in. thick is inserted between the cast-iron cap and the bottom of cross-girders, and about twelve $\frac{7}{8}$-in. bolts are used in the connection of cross-girders to columns. This detail, of course, does not fix the tops of columns in such a rigid way as the details used on the Union Loop of Chicago, but the connection is as strong in every way as it is possible to make it when the columns are cut off below cross-girders. The writer could find none of the bolts in these connections loose, and he was informed by others that only a very few of these bolts had ever been replaced.

"No diaphragms are used between the cross-girders directly over the columns, and it occurred to the writer that if a solid diaphragm had been put in between the two cross-girders, directly over the center of the column, riveted to both girders and bolted to the top of column, it would practically have made a fixed end of the top of column, so far as the cross-girders are concerned. Such details for tops of columns cannot be commended, because the only rigidity which can be obtained in such connections is due to the ability of the bolts to resist direct tension, and certainly better results can be obtained at much less cost by running up the columns and riveting the cross-girders into them.

"*12. Paltry Brackets Connecting Cross-Girders to Columns.*—The brackets used on the Second Avenue line are small cast-iron sections curved to circular form, and bolted at one end to the cross-girders and at the other to the column. If these brackets were put on merely to improve the appearance of the structure, they may, to a certain extent, be said to fill the purpose for which they were intended, but if they were intended to serve as braces to aid the column in any way, they are certainly useless.

"*13. Proportioning Columns for Direct Live and Dead Load and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.*—The columns used on this Second Avenue line are of Phœnix sections and contain ample metal to resist all stresses that ever come upon them if they were firmly fixed at the tops in both transverse and longitudinal directions. The vibration in this structure is not due to lack of metal in columns, but to numerous defective details as outlined previously. While there is considerably more vibration in this structure than there should be, it is, nevertheless, the most rigid and durable of any of the elevated roads in New York, excepting the Suburban Rapid Transit line and the City Hall approach, and the better condition of this Second Avenue line is due largely to the great amount of metal used in its construction. As nearly as the writer can estimate the weight of this structure, it contains about 30% more metal per lineal foot of structure than does the Union Loop of Chicago. A large portion of this metal is in the columns and cross-girders.

"As before stated, the Phœnix columns on this line are often burst by the freezing of accumulated water on the inside of the columns. This water must get into the column by the bolt holes at top, through which the bolts pass that attach the cross-girders to the column, also through the holes in the sides of columns through which the bolts pass that connect the curved cast-iron brackets.

Mr. Waddell.

"*14. Omission of Diaphragm Webs in Columns Subjected to Bending.*—The Phœnix column requires no diaphragm and is well adapted to carry shear in any direction.

"*15. Ineffective Anchorage; 16, Column Feet Surrounded by and Filled with Dirt and Moisture; 17, Inefficient Bases for Pedestals.*—The bases of the columns are made of cast iron, and into these cast-iron bases the column is set in cement or rust grouting. The joints between the columns and castings are in good condition, and there are no evidences of any springing or movement of the columns. The cast-iron bases are extended far enough above the ground to prevent the dirt and moisture from accumulating around the steel column. The columns are not badly rusted, considering the length of time this structure has been built. Each of these cast-iron bases is anchored to the masonry by four anchor bolts which extend to the bottom of pedestal. The anchorages are so strong that the columns and pedestals would act as one piece if tested to destruction. There have been but few if any repairs made to the anchorages and pedestals, nor has there been any settlement of the foundations. It is the opinion of the writer that the pedestals, bases and anchorages are first class, and if all parts of the structure were as well designed as these portions there would be but little adverse criticism to make.

"From the foregoing you will note that the writer does not agree with Mr. Clarke's statement that the Second Avenue line conforms in general design to all of the seventeen essentials named in your paper, and maintains that Nos. 1, 2, 5, 8, 9, 10 and 11 of the defects named do exist in a very distinct form in the Second Avenue line, and that the evil results of such defects are plainly shown by the action of the structure under loads and by the necessity for repairs which are being made from time to time.

"Mr. Clarke's figures of $319 per mile per year seem a large amount to pay out for repairs to metalwork alone, exclusive of painting and trackwork. The writer is of the opinion that on a structure designed like those shown in your paper, the cost of repairs to metalwork alone would be practically nothing for the first 20 or 30 years; and with no increase in the live loads, the life of such a structure, kept well painted, would be indefinitely long.

"The writer wishes it to be understood that he does not criticise the design of the Second Avenue line as not being fully up to the standard of good construction at the time it was built, and he appreciates the fact that the art of steel construction was in its infancy 20 years ago, and that it has been by a process of evolution that the designs of to-day are so far superior to those of the earlier days.

"*General Criticism of All the Elevated Railways in New York and Brooklyn.*—In accordance with your request, the writer extended his investigations to all the elevated railways in New York and Brooklyn, and in the following report will take up the 17 defective points mentioned in your paper, and apply them to all of these lines, and will show that some of these exist in all of the structures mentioned, and all of them in some of the structures.

"*1. Insufficiency of Rivets for Connecting Diagonals to Chords of Open-Webbed Girders.*—The longitudinal girders on the Third Avenue line were originally made with single intersection webs, each diagonal being composed of two angles; but with increased live loads and constant traffic these girders began to wear out so rapidly that it became necessary to strengthen them. This strengthening was done by putting in another set of diagonals, each diagonal being composed of two

Mr. Waddell. flat bars which pass between the original angle diagonals at their centers and are riveted to them at their intersection by one rivet. No connecting plates are used in any of the connections of diagonals to chords, and even with the additional set of diagonals the girders are weak.

"If the loads were equally distributed between the two sets of diagonals, the number of rivets in the connections of diagonals to chords would be ample; but, as the added diagonals are capable of taking tension only, they are of but little value, and the end connections are still overstrained, as is shown by the number of loose rivets to be found in them.

"The construction of the longitudinal girders in the Ninth Avenue line is very similar to that of the Third Avenue line.

"The longitudinal girders in the Kings County Elevated are of much better design; for in most cases plenty of rivets are used, as the diagonals are connected to web plates in top and bottom chords.

"*2. Failure to Intersect Diagonals and Chords of Open-Webbed Girders on Gravity Lines.*—On none of the lines where lattice girders are used has there been any attempt to intersect the diagonals on gravity lines, and this is no doubt one of the great causes for the wear on these girders."

"*4. Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.*—No webs are used in the top chords of longitudinal girders in any of the New York lines, but as the panels are very short in most instances, the bending on top chords from wheel loads does not produce excessive strains in them.

"On the Kings County Elevated, heavy web plates about 15 ins. wide are used between both top and bottom chord angles, which are ample to resist the bending from wheel loads in addition to the direct stresses. The connections are eccentric, and the stresses due to the bending from eccentric connections are greater than those from the bending due to loads on top chords.

"To make a comparison of the details of the longitudinal girders used on the Union Loop in Chicago, and some of the New York and Brooklyn elevated roads, the writer herewith gives some typical details of the different designs in Figs. 44, 45, 46 and 47.

"By a careful inspection of Fig. 44, which shows the details of the longitudinal girders used on the Union Loop, it will be seen that all diagonals intersect on the center-of-gravity lines of the chords, thus eliminating all secondary stresses, while the diagonals of girders shown in Figs. 45, 46 and 47, do not intersect on gravity lines; consequently large secondary stresses are produced in all said designs.

"It will also be noticed that in the Union Loop design ample provision has been made for bending on top chords, by providing a web plate between the two top chord angles, that large connecting plates are used for connecting diagonals to bottom chords, and that more rivets are used in all connections of diagonals than in the girders of the other structures.

"The girders for the Kings County Elevated, Fig. 45, have heavy web plates in top and bottom chords, and, although more metal is used in these girders than in those for the Union Loop, none of the diagonals intersect on gravity lines. The end detail of these girders which furnishes the bearing on cross-girders is very eccentric, and it will be seen that on the section on *AB*, Fig. 45, there is a large bending moment which must be taken up by the top chord and the reinforcing

Mr. Waddell.

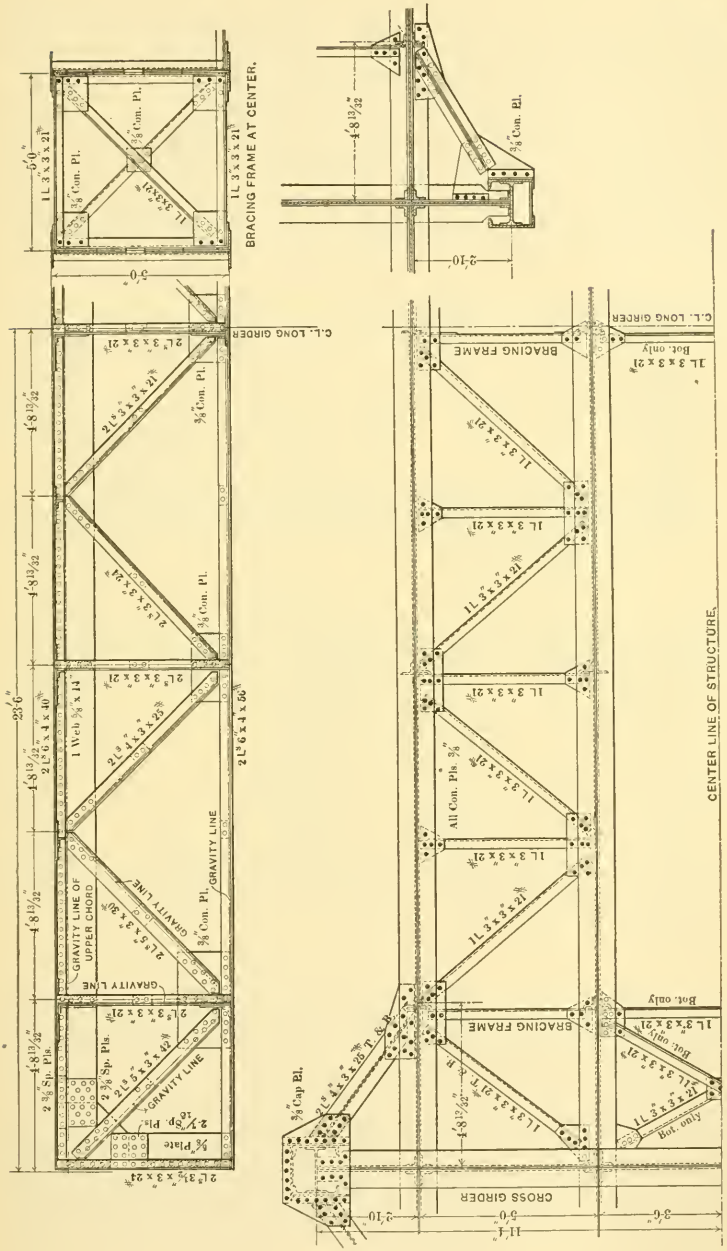


FIG. 44.

Mr. Waddell. angles at the end; but the reinforcing angles are cut off so near the point of maximum bending that there is a great shear on the few rivets back of the section line AB which could easily have been avoided by extending the reinforcing angles back 12 or 15 ins. farther.

"Fig. 46 shows the details of the longitudinal girders on the Second Avenue line, which have been considered previously.

"Fig. 47 shows the details of the longitudinal girders on the Third Avenue line since they have been re-enforced. The eccentric connections, light top chord section, and few rivets in all connections should be noted.

"There is one commendable feature of the girders shown in Figs. 45 and 46, which that shown in Fig. 44 does not possess, and that is

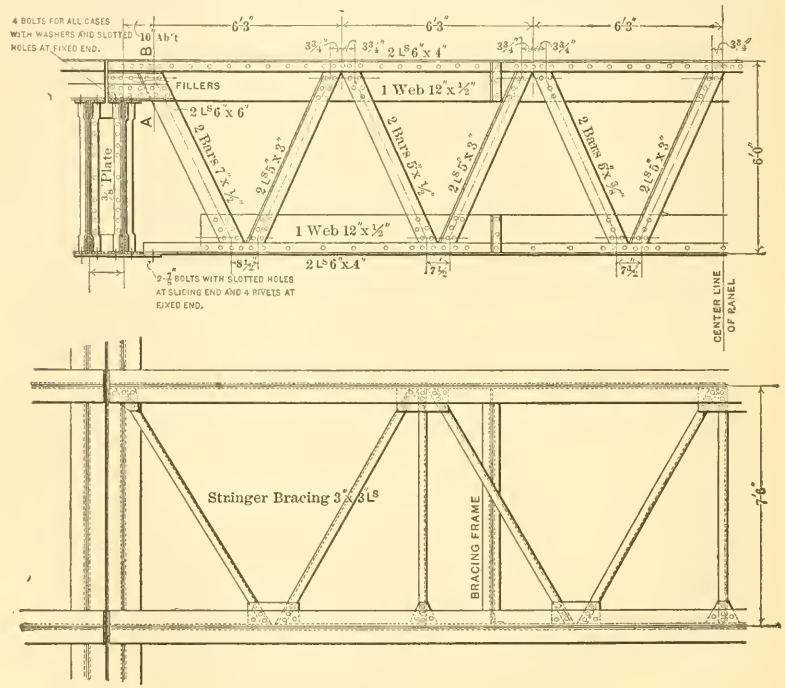


Fig. 45.

the projection of the top flange angles above the cross-girders. This arrangement of girders gives an unbroken surface of longitudinal girders on which to lay the ties.

"*5. Insufficient Bracing on Curves.*—No special lateral bracing is used on curves of any of the New York and Brooklyn lines.

"*6. Insufficient Bracing between Adjacent Longitudinal Girders.*—On the Second Avenue, the Third Avenue, and the Ninth Avenue lines, both the top and bottom flanges of adjacent longitudinal girders are braced together with angles connected to girders by two rivets, no connection plates being used in any case. On all of these lines there are loose rivets in the bracing connections.

Mr. Waddell.

"7. *Pin-Connected Pony Truss Spans and Plate Girders with Unstiffened Top Flanges.*—Pony truss spans are used on the greater portion of the Sixth Avenue line, and of all the structures which the writer has examined, this one is undoubtedly in the worst condition. The evidences of wear and tear are too numerous to mention. The vibration is excessive, and loose rivets are plentiful.

"8. *Excess of Expansion Joints.*—With two or three exceptions, all of the lines in New York and Brooklyn have expansion joints at every panel. Two of the exceptions are the Fifth Avenue line in Brooklyn, in which the sliding ends are placed at every third bent, or about 150 ft. apart, and the Suburban Rapid Transit line, in which they are placed at every fifth bent, or about 225 ft. apart. The longitudinal rigidity gained by spacing the sliding ends as in the last-named structure is

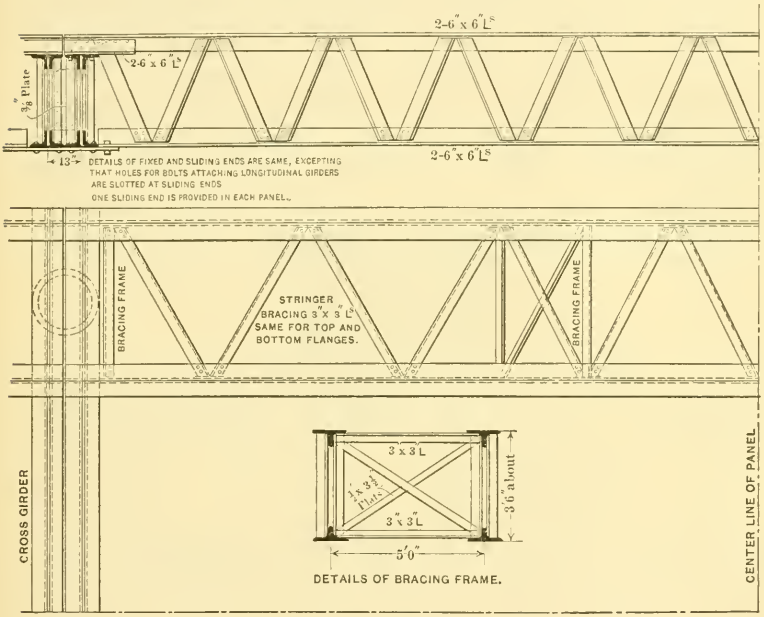


FIG. 46.

very noticeable by comparing them with the structures in which the expansion joints are placed in every panel.

"9. *Resting Longitudinal Girders on Top of Cross-Girders Without Riveting Them Effectively Thereto.*—Various details are used on the different lines for attaching the longitudinal girders to cross-girders. The details adopted on the Kings County, the Second Avenue, and the Third Avenue lines are shown in Figs. 45, 46 and 47, and these are typical of those used on all of the older lines. On the Suburban Rapid Transit line in New York, and the Fifth Avenue line in Brooklyn, the longitudinal girders are riveted into the cross-girders, the top flanges of the former passing beneath those of the latter.

"The connections of longitudinal girders to cross-girders on the older lines are not designed to resist properly the thrust from braked trains, as will be seen from Figs. 45, 46 and 47.

Mr. Waddell. "A great many of the rivets and bolts attaching the longitudinal girders to the cross-girders work loose, especially those at bottoms of longitudinal girders.

"*10. Cross-Girders Subjected to Horizontal Bending by Thrust of Trains.*—On none of the lines in New York or Brooklyn is any special bracing used to carry the thrust from braked trains directly to the columns, and thus relieve the cross-girders from the transverse bending which comes upon them. A slight semblance of such bracing is used on the Kings County Elevated, but the struts are of small single angles, which are placed in planes of bottoms of longitudinal girders only, and are not capable of carrying the stresses which come upon them.

"On most of the older structures the cross-girders are all double, consequently they are capable of carrying more horizontal bending than are single-webbed girders, and when the columns are placed

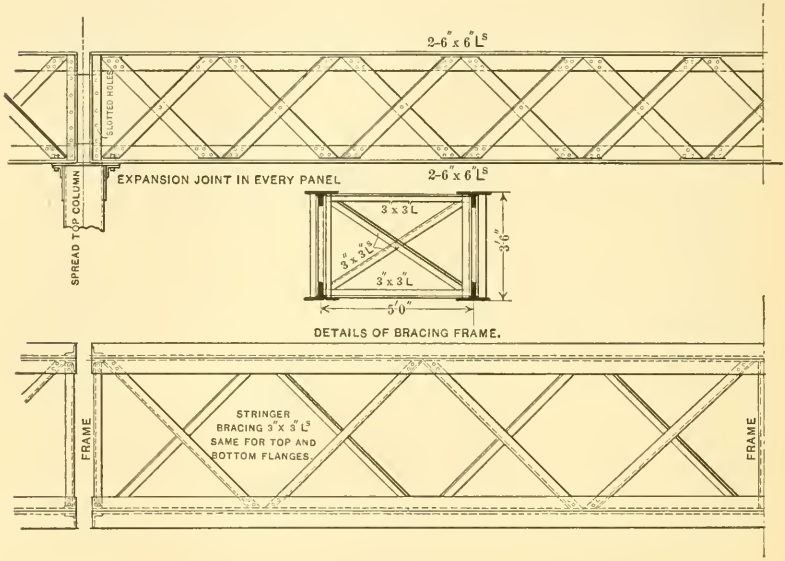


FIG. 47.

beneath or quite near the tracks, they are strong enough to carry the thrust to the columns; but where columns are set on curbs, the bending effect of braked trains is noticeable in the vibrations of the structure, and in some cases by the canting of the cross-girders.

"The bracing used on the Union Elevated Railway of Chicago to take up the thrust from braked trains, also to fix the tops of columns, is shown in Fig. 44. From some of the discussions, the writer believes it will be interesting to give in this connection the method used in determining the size of these struts and the strength of their details.

"Let us assume the span length to be 50 ft.; live load = 1 800 lbs. per lineal foot of track (equivalent load for 150 ft. span); total live load on one panel per track = 50 x 1 800 = 90 000 lbs.; coefficient of friction = 0.20; longitudinal thrust = 90 000 x 0.20 = 18 000 lbs.; distance from center to center of columns = 22.66 ft.; thrust on one

column $= \frac{18\,000 \times 17.33}{22.66} = 13\,770$ lbs.; the depth of longitudinal girder is 5 ft., unsupported length of column = 16 ft. (see Fig. 48). Mr. Waddell.

"As this bracing is designed to fix the tops of columns, and as the bottoms of columns are firmly fixed by the anchorages, the lever arm is equal to one-half the unsupported length of column, or 8 ft.

$$\text{Stress on lower strut} = \frac{13 \times 13\,770}{5} \sec. \theta = 42\,246 \text{ lbs.}$$

$$\text{Stress on top strut} = \frac{8 \times 13\,770}{5} \sec. \theta = 25\,998 \text{ lbs.}$$

"The unsupported length of these struts is about 4 ft. Least radius of gyration, two 4 x 3-in. 25-lb. angles = 1.2. Therefore, $\frac{l}{r} = \frac{48}{1.2} = 40$. Hence, these struts are good for 12 000 lbs. per square inch. They are, therefore, strong enough to fix the tops of columns. From Fig. 44 it will be seen that eight rivets are used for the bottom struts; then stress on each rivet in the connection for bottom strut = $\frac{42\,246}{8} = 5\,281$ lbs., and for those in the connection for top strut =

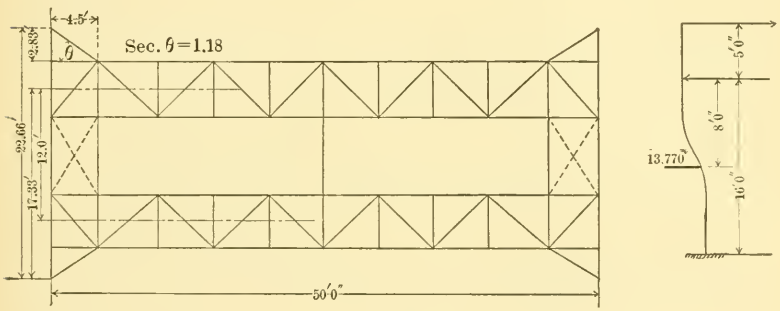


FIG. 48.

$\frac{25\,998}{6} = 4\,333$ lbs. These stresses are well within ordinary working intensities. From these calculations, it will be seen that the tops of columns are fixed by these struts, and that all members and details are strong enough to take care of the stresses produced by the assumed thrust of 0.20 of the live load.

"Having thus shown the method used in determining the size of struts required to fix the tops of columns, the effect of this horizontal thrust will now be used in proportioning a column.

"Assuming the same span length as before, we have the following:

"Live load = 2 440 lbs. per lineal foot of track (equivalent live load for 50-ft. span).		
"Dead load = 650 lbs. per lineal foot of track.		
"Total = 3 090 lbs. " " "		
"Total load on one column from longitudinal girders	3 090 x 50 =	154 500 lbs.
"Weight of one column and half of one cross-girder.	6 500	"
"Total direct load on one column	161 000	"

Mr. Waddell. "The total longitudinal thrust on one column, as given above, is 13 770 lbs. One-half unsupported length of column = 8 ft. or 96 ins. Bending on column = 96 x 13 770 = 1 321 920 inch-pounds. Section used for column { 2 15-in. 100-lb. channels. 1 15-in. 123-lb. I-beam. } Area of section = 32.3 sq. ins.

"The web of I-beam is placed parallel to center line of structure.

"The moment of inertia of section = 1 300 net.

"Therefore the stress on extreme fiber

$$= \frac{8 \times 1\,321\,920}{1\,300} = 8\,135 \text{ lbs.}$$

"Stress from direct load = 5 000 "

"Total stress on extreme fiber due to combined direct load and bending moment = 13 135 "

which is allowable under such an unusual loading, as $\frac{l}{r}$ is less than forty-five.

"From the foregoing calculations it will be seen that all parts of the structure are designed to resist properly the assumed horizontal thrust; and it is interesting to note also that, although all possible combinations of stresses under the most unfavorable conditions are properly taken care of, the structure does not weigh as much per lineal foot as some of the older designs in which no provision is made for such stresses, although they are liable to occur.

"*11. Cutting off Columns Below the Bottom of Cross-Girders and Resting the Latter Thereon.*—The columns of nearly all the structures in New York and Brooklyn are cut off below the bottoms of cross-girders, except in the City Hall approach in New York, and on a portion of the line on Broadway in Brooklyn. On the City Hall approach the columns are built of two 15-in. channels, laced together with double-riveted lacing. The inner channel is cut off below the bottom of cross-girder, and the outer channel is extended to the top of cross-girder, the latter being riveted into this channel. This construction is certainly much better than that used on most of the New York lines; but the connection would be more rigid if both channels were extended to top of cross-girder, and if a diaphragm were placed between the two channels and extended down to the bottom of the curved bracket beneath the cross-girder.

"The detail used for attaching the cross-girders to columns on the Rapid Transit line, New York, and given by Mr. Berger in Fig. 35, is certainly a good one, as it makes the cross-girder and column practically continuous, and is at the same time comparatively easy to manufacture and erect.

"On all lines where Phœnix columns are used, the columns are cut off beneath the cross-girders, and are provided with cast-iron caps to which the cross-girders are attached by means of bolts. This style of construction, with its defects, was discussed in connection with the Second Avenue line.

"On the Third Avenue line the columns are composed of two 15-in. channels connected with double-riveted lacing, and are flared out at the top to receive the longitudinal girders which rest thereon. The connections between columns and girders are very weak, and are not capable of resisting properly the longitudinal thrust.

"The curving of channels at tops is objectionable, for, according

to the reports of shop inspectors, the channels often crack while being bent. Another objectionable feature of this style of column is that where the concentrations from longitudinal girders come upon the edge of the column, there is very little metal to carry the load. There are many failures in the details at tops of the columns on the Third and Ninth Avenue lines, and in many instances bent plates have been used to reinforce them. Mr. Waddell.

"The bolts and rivets which attach the longitudinal girders to the tops of columns fail in a great many instances, and in some cases the tops of columns have been reinforced with bent plates. A portion of the Ninth Avenue line is constructed in the same manner. On the Fifth Avenue line in Brooklyn the columns are built of two 15-in. channels with double riveted lacing bars. The inner channel is cut off below the bottom of cross-girder, and the outer one is extended up about 18 ins., and riveted to end of cross-girder. The detail is similar to that used on the City Hall approach, but not nearly so good.

"*12. Paltry Brackets Connecting Cross-Girders to Columns.*—The brackets used on the Second Avenue line have been described, and the same style of brackets is used on all structures having Phœnix columns.

"The columns on Third Avenue are flared out at top and thus form a kind of bracket. The brackets on the Sixth Avenue line are made of a single 3-in. or 4-in. T-iron and connected to columns and cross-girders by four small rivets about $\frac{5}{8}$ in. in diameter, at each end. These brackets are absolutely useless so far as providing any lateral rigidity to the structure is concerned.

"On the Kings County Elevated the brackets are made of two 3 x 3-in. angles connected to cross-girders and columns by three rivets or bolts. These brackets are very weak, and add but little, if any, rigidity to the structure.

"A portion of the Fifth Avenue line in Brooklyn has brackets composed of two 6 x 6-in. angles attached to cross-girders and columns by four rivets at each end of strut. These brackets are strong enough to take care of any stress that comes upon them. On some portions of this line, where the structure is only of ordinary height, the brackets are omitted, and as the connection between cross-girders and columns is weak, as previously described, the tops of columns are almost free ended. This portion of the structure is very vibratory, in fact the writer believes the vibration at the Sixteenth Street station on this line is greater than at any other elevated station in New York or Brooklyn.

"The City Hall approach has curved brackets with solid webs which serve their purpose well.

"The brackets on the Suburban Rapid Transit line are made of two 4 x 3-in. angles, bent at ends onto cross-girders and columns, and connect by six rivets. These brackets, and the superior details used to connect the cross-girder to column help to make the structure rigid transversely.

"*13. Proportioning Columns for Direct Live and Dead Loads and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.*—If all details were made so as to fix properly the tops of columns in both transverse and longitudinal planes, the sections used for the columns on most of the lines in New York and Brooklyn would be strong enough to carry satisfactorily all the loads that could ever come upon them.

Mr. Waddell. "*14. Omission of Diaphragm Webs in Columns Subjected to Bending.*—A great many of the columns used on the various lines are of Phœnix section, and consequently do not require diaphragms, and on several lines where channel columns are used the lacing is double riveted. The writer could see no signs of failure in any of the lacing on columns, even where single riveted lacing is used.

"*15. Ineffective Anchorages.*—The writer believes that the anchorages on nearly all the lines he examined are strong enough to carry satisfactorily all the combinations of stresses which ever come upon them.

"*16. Column Feet Surrounded by and Filled with Dirt and Moisture.*—There are a number of designs used for column feet on the different lines in New York and Brooklyn, but in nearly all cases the bases are made of cast iron, and are extended well above the surface of the ground, serving as fenders where the columns are placed in the street. The feet of the Phœnix columns are, in general, as well preserved as could be expected considering the age of these structures, and the little attention these bases have received. If the feet of columns were kept properly painted, and if the joints between the columns and the cast-iron bases were kept well filled with grouting, these bases would be entirely satisfactory.

"The bases of columns on the Third and Sixth Avenue lines and on a portion of the Ninth Avenue line are very different from those used with the Phœnix columns. As well as the writer could determine, these columns, which are in the street, are set in a cast-iron base which is entirely below the surface of the pavement, and a separate cast-iron fender is used above. These bases are not so satisfactory as those previously described, and in many cases the fenders are broken and the feet of columns are badly rusted.

"The column bases on the Suburban Rapid Transit line are made of cast iron and the bottoms of columns are filled with grouting. The feet of these columns are in good condition.

"On a portion of the line on Broadway in Brooklyn, the bases are made of cast-iron and are solidly riveted to the feet of columns. These castings rest on stone pedestals which project 18 ins. or 2 ft. above the pavement and serve also as fenders. These column feet are in excellent condition; the connections of columns to bases are very strong, and their bases are in turn attached to pedestals by four anchor bolts. There is no place for moisture or dirt to accumulate, and for durability and efficiency these bases are probably superior to those used on any of the other elevated lines in New York or Brooklyn.

"*17. Insufficient Bases for Pedestals.*—The writer could not secure much information concerning the pedestals, but so far as he could learn there has never been any trouble from the settlement of foundations, and therefore it is probable that ample bases have been provided for the pedestals.

"*18. Neglect of Painting the Metalwork.*—It is surprising to note the false economy practiced on all the elevated railways in New York and Brooklyn, by failing to keep the metalwork properly painted. It is safe to say that there is not a single line which is not badly in need of repainting.

"Without doubt the almost unmolested erosion of the metal on the older structures has done more to destroy them than the wear and tear due to both the heavy traffic and the excessive vibration from defective details. It is only a matter of time, and not a very long time either, unless some very effective means are employed to arrest the

ravages of rust, until the older structures will have to be rebuilt. It is indeed remarkable that metalwork, the value of which runs up into millions of dollars, should be left to rust away, when a comparatively small sum of money, spent at the proper time and for the right kind of painting, would prolong the life of the structure indefinitely. The writer believes that the subject of painting should have received more consideration in your paper, as it is certainly a most important one. Engineers should certainly use their influence to prevent such great losses to the companies, which losses are as sure to come from lack of painting as from faulty details." Mr. Waddell.

From what Mr. Hedrick says it will be seen that Mr. Clarke was a trifle hasty when he stated that the Second Avenue line of New York "conforms in general design to all of his (the author's) sixteen 'essentials,' although in details there are many differences." In truth, there are very few of said essentials of good construction that were not violated in the design of this Second Avenue line; although there is this to be said in its favor—a plentiful, or, strictly speaking, an extravagant, use of metal reduces considerably the magnitude of the ill effects of the violation of first principles of design; and, considering the lack of knowledge about structural metalwork at the time it was designed, it is a creditable piece of engineering work. Nevertheless, this is no reason why it should continue to be a model for future elevated railroads.

Treated Versus Untreated Timber.—It appears that Mr. Stuart and Mr. Belknap question the correctness of the data used in comparing the real values of vulcanized and untreated timber, so it behooves the author to make good his premises.

Most of his information concerning vulcanized yellow pine was obtained in conversation with the late Colonel Hain, who was for many years general manager of the Manhattan Railway Company. Unfortunately there is no documentary evidence to verify the conversation mentioned, but the author is able to give the following extract from a letter by Colonel Hain to Professor F. Holbein, of Berlin, Germany, which will substantiate the statement that the former approved of vulcanized timber for elevated railroads:

"We first began the use of vulcanized wood in the spring of 1883. One million feet of vulcanized cross-ties and planking was placed on the line of our road that year, expressly to give it a fair trial on its merits. After the lapse of six years, a careful and critical examination was made of the vulcanized material laid in 1883. We found it entirely free from decay, and as sound and sweet as the day it was laid. There were no indications of decay at the end of the vulcanized planking, while the planks and cross-ties not treated, placed on the structure at the same time, were decayed at the ends and where they were nailed or bolted to the supporting timbers.

"Since the foregoing examination, we have been using vulcanized material exclusively on the line of the road. Actual experience has satisfied us that vulcanizing is far superior to any other known treatment for prolonging the life of timber. We find that vulcanized ma-

Mr. Waddell. terial neither wears out nor decays. We have had no occasion to take up any of it since we commenced its use.

"Our experience with creosoted ties proved unsatisfactory. Creosoting seems to soften timber and weaken its spike-holding quality. We have found great trouble in keeping spikes in place, especially on curves. Spikes in vulcanized wood we find are as firmly fixed after the lapse of ten years as when first driven.

"Vulcanized wood does not seem affected by wind, rain, heat or sun. Before we adopted vulcanized wood it was necessary to constantly employ 150 men painting our structure. Since its adoption, we have only 60 painters, who work on the iron part of the structure exclusively. Vulcanized wood needs no paint to protect it.

"The average life of untreated ties and timber on our structure has been about five to six years."

Here is a distinct disagreement between Mr. Stuart and Colonel Hain concerning the life of untreated timber on elevated railroads. Mr. Stuart challenges the author's assumption that the life of such timber is as short as seven and a half years, while Colonel Hain says that on his lines it has been about five or six years. The author's experience with timber trestles in various parts of the United States indicates a life of from five to eight years for untreated yellow pine; although in certain cases a couple of years longer duration has been obtained by renewing defective parts and bolstering up the structure in different ways.

In order to satisfy Mr. Belknap's doubts concerning the efficiency of the vulcanizing process and the comparative values of vulcanized and untreated timber, the author has collected quite a mass of written evidence, extracts from which are given in the appendix.

Bearing Capacity of Chicago Soil.—The author regrets that, as pointed out by Mr. Weston, his statement that Mr. Rowe found the safe load per square foot for Chicago soil as low as 1 000 lbs., should cause any misconception concerning the character of the foundations for the Northwestern and Union Loop Elevated Railroads. Mr. Rowe's discussion, though, will clear up any such misunderstanding.

Best Style of Anchorage for Columns.—Answering Mr. Nichols' statement that the author duplicated in his column anchorage for the Sioux City train-shed the corresponding detail used for the St. Louis Union Depot, the author would reply that the design for the former was made in June, 1891, before anyone did any figuring at all on the St. Louis train-shed.

Best Sections for Columns.—Answering Mr. Nichols' statements that no one has ever made a very satisfactory column from I-beams, and that the Z-bar column is "unsatisfactory when it comes to connections with girders or with column feet," the author must take issue with him; for it would be difficult to evolve a more satisfactory column for street work than that formed of two channels with an I-beam between, as used throughout the Union Loop. The author does not mean satisfactory to the manufacturer or to the erector, but satisfactory to the party who pays for and operates the structure. These

columns are not only extremely rigid, but also are well calculated to resist deformation from the heavy blows to which they are occasionally subjected by the street traffic. As for the Z-bar column of the Northwestern Elevated, one could not ask for better connections for detailing; and certainly the column thus far has proved satisfactory in every respect, although it has not yet been subjected to the test of traffic. Mr. Waddell.

Replying to Mr. Nichols' question as to why the columns for Designs 12 and 13 have larger sections than those for Design 3, the author would state that the latter design involves the use of longitudinally braced towers, while the other designs do not. In Design 3 there is only direct vertical load on the columns, while in the other designs there are both vertical load and cross bending.

Mr. Connor criticises the Z-bar column on account of its expense in manufacture; but when one considers that when the Northwestern metalwork contract was let the pound price bid was very much lower than any price previously tendered on elevated work, notwithstanding not only the alleged difficulty in manufacturing the columns, but also the reaming clause, the importance of his criticism reduces practically to zero. It must be remembered that the ultimate object in designing metalwork is to obtain results and not to keep down to the lowest possible limit the cost of manufacture.

The columns of two channels with flared ends advocated by Mr. Connor are defective for two reason: first, the bending is injurious to the metal, and, second, the bearings for the longitudinal girders are inadequate. Mr. Hedrick refers to these points in his report upon the New York and Brooklyn elevated railroads.

Best Style of Expansion Joint.—The author never claimed that he evolved his design for expansion pockets out of his inner consciousness. It represents simply an improvement on the older designs, in that the load from the longitudinal girder is applied as closely as practicable to the web of the cross-girder, and in that the weight of metal required is reduced to about a minimum, with due regard for both direct load and bending caused by eccentricity.

Distance Between Expansion Joints.—In respect to the best distance between expansion joints, the author would call attention to the fact that when the columns are fixed at top and bottom, the effect of variation of temperature is greater than where one end is loose, and that the extremes of temperature in Chicago are somewhat greater than those at New York. On these accounts he still prefers to adhere to 150 ft. as the regular limit, with an occasional length of 200 ft. at most, where the conditions necessitate it. The author's calculations were based upon an assumed extreme of expansion and contraction equal to 1 in. in 100 ft., although he considered it probable that not much more than three-quarters of this would be found after erection.

Mr. Waddell. *Superelevation on Curves.*—Mr. Nichols must remember that it is intended to operate the Northwestern Elevated at much higher speed than ever before adopted for an elevated railroad, hence the author's "apology for a compromise between theory and practice in using low elevations of the outer rail on curves."

Answering Mr. Nichols' surmise that none of the connections of the author's columns to girders are either very simple or thoroughly effective, the author begs to submit through Mr. Hedrick's report some detail sketches of the tops of the columns for the Loop. From these sketches it will be seen that the column tops are connected rigidly by an ample number of rivets to substantial struts that form part of a complete system of lateral bracing, and that the connecting rivets are in direct shear. It is shown by these sketches that "close adherence to the scholastic methods has not led to the retention of some of the antique errors of girder construction."

It is evident from Mr. Nichols' figures that the spans on his Brooklyn Elevated could have been made a trifle shorter, so far as economy is concerned; however, if he will deduct the cost of all the lateral bracing, and will compare that of the longitudinal girders alone with that of the bent, he will not find as much difference as 30 per cent. It is very easy to see that if the cost of a bent be practically constant for small changes in length of longitudinal girders, and if the cost per foot of the latter vary directly with the span, the greatest economy will exist when the cost of a bent is equal to the cost of the longitudinal girders of one span.

In order to reply to Mr. Nichols' claim that an earth embankment with concrete retaining walls would be cheaper than the structure adopted for the Northwestern Elevated, the author has made such a design with an estimate of cost, and finds that, on the contrary, the embankment would cost fully 7% more. The data for the estimate are as follows:

Height of embankment above street, 16 ft.; width of embankment out to out, 48 ft.; thickness of both wall and buttresses at top, 18 ins.; thickness of wall at top of footing course, 3 ft.; that of buttresses at same elevation, 6 ft.; width of footing course for wall, 5 ft., and that for buttresses, 8 ft.; depth of foundation, 5 ft.; front face of wall vertical; rear face stepped off by 6-in. offsets; three horizontal $1\frac{1}{2}$-in. rods used to tie together each pair of opposite buttresses transversely to line; vulcanized ties 8 ins. x 8 ins. x 9 ft. spaced 2 ft. centers; price of concrete $7 per cubic yard; cost of metal 2.5 cents per pound; cost of earth in place 30 cents per cubic yard; cost of excavation, including back-filling, 50 cents per cubic yard; cost of rails for both cases, $2 per lineal foot of track; cost of vulcanized timber in place $36 per M., B. M.

The length of line considered is one city block of 292 ft., of which

the street takes 72 ft. and the alley 20 ft., leaving exactly 100 ft. as the length of each retaining wall. As it is not practicable to tie together opposite buttresses in the end walls, the entire end walls were made of the same section as the buttresses of the side walls. Mr. Waddell.

The following is the detailed estimate of cost:

Two Embankments.

Concrete	1 502 cu. yds., at	$7 00	$10 514 00
Earth	4 187 " "	30	1 256 10
Excavation	782 " "	50	391 00
Ties	400 "	1 75	700 00
Rails, etc.	800 ft. of track "	2 00	1 600 00
Metal	16 400 lbs. "	2.5 cents	410 00
Grouting around the rods			200 00
Total			$15 071 10

Metal Structure over Alley.

Metal	20 000 lbs. at	2.5 cents	$500 00
Floor	20 ft. "	$23 00	460 00
Total			$960 00

Metal Structure over Street.

Metal	132 000 lbs. at	2.5 cents	$3 300 00
Floor	72 feet "	$23 00	1 656 00
Pedestals	6 "	100 00 (av.)	600 00
Total			$5 566 00

Summation.

Embankment	$15 071 10
Over alley	960 00
Over street	5 556 00
Total	$21 587 10

or, $73 93 per lineal foot.

Cost of Metal Elevated.

Metal, per foot, 1 765 lbs. at 2.5 cents	$44 13
Floor and rails, per foot	14 32
Pedestals (32 at $96) ÷ 292	10 52
Total cost per lineal foot	$68 97

Mr. Waddell. The schedule prices used in these estimates are the same as those adopted for the preliminary estimates of cost for the Northwestern Elevated. Moreover, they have since proved to be almost exactly right, except that the concrete in foundations was somewhat cheaper; but as the concrete for the walls will be more expensive than that in the pedestals on account of the more complicated and larger forms required and the smooth finish of the exterior, it has been considered best to let the price stand unchanged.

The difference in cost per foot in favor of the metal structure is $4 96, or a little over 7 per cent.

The adoption of the embankment design would increase the cost of right-of-way almost as much as it would that of the construction, for, although it would not affect the price of the land occupied by the structure, it would affect the amounts to be paid as damages to adjacent property. These will average as high as 30% of the cost of the land occupied by the structure. The reason for the smaller damages for a steel structure is that with it the railroad company is able to grant to adjacent property owners access to the damaged property from the right of way, which could not be done were the embankment design adopted. The author has been informed by one of the officials of the Northwestern Elevated, who is best posted on right-of-way matters, that the additional amount to be paid for damages on account of the embankment design would be not less than 15 per cent.

The advantages of the embankment design are, first, a reduction in cost of painting to one-third of that for the metal structure, and, second, lowering the grade about 3 ft. To offset these there are the extra first cost of construction and right of way, the more rapid deterioration of the ties in the embankment, and the prevention of use of ground beneath the structure for storage purposes, small shops, etc. This last item is an important one, especially as the ground will become more and more valuable for such purposes as the city continues to grow and develop in the neighborhood of the line.

Answering Mr. Nichols' criticism of the design for anchor bolts, take the worst case on the Loop, where the spans are, say, 50 ft. long, making the distance between expansion points 150 ft., and load two of the three spans to the maximum, making the live load on one track about 200 000 lbs., for which the thrust would be 40 000 lbs., or 13 333 lbs. per bent. The spacing of tracks being 12 ft. and that of the columns 22 ft. 8 ins., the portion of the 13 333 lbs. going to the nearer column would be about 10 000 lbs. The greatest unsupported length of column, measuring from the under side of the thrust strut to the bottom of the base plate, is 25 ft.; and, as the column is fixed at both ends, the point of contraflexure will be at the middle, making the lever arm for the thrust 150 ins. and the overturning moment 1 500 000 inch-pounds.

Mr. Waddell.

In order to make all the conditions as bad as possible for the detail, no live load will be placed on the bent considered, and as the dead load per track, including weight of bents, is 800 lbs. per lineal foot, the dead load on the column is 40 000 lbs. It is difficult to say where is the center of upward pressure to resist this weight; but, if it be assumed at the same distance from the axial plane as are the anchor bolts, or $9\frac{1}{2}$ ins., no great error will be made. This makes the righting moment 380 000 inch-pounds, leaving for the net overturning moment 1 120 000 inch-pounds; dividing this by the 19 ins. between opposite anchor bolts gives about 59 000 lbs. as the stress on the two anchor bolts. As these are $1\frac{1}{2}$ ins. in diameter, the intensity on the metal will be about 17 000 lbs., which, though high, is not excessive.

As this is the worst possible case, and as all the anchor bolts for the line pedestals are of the same diameter, there is evidently sufficient strength in all of said bolts; and, moreover, there is no great waste of metal in the anchor bolts for the shorter columns. Again, on various accounts one would not think of using bolts of much less diameter on account of possible future rust, especially as the diameter is reduced at the root of the thread.

The next matter is whether the anchor bolts project far enough into the concrete, as Mr. Seaman, Mr. Berger and others appear to question the propriety of not carrying them down to the bottom. In the first place it must be noticed that the mass of concrete is truly monolithic; and, as the function of the bolts is to make the column and the concrete act as one piece in resisting overturning, it will suffice if the tensional strength of the concrete at the end of the bolts be as great as that of the acting bolts.

Now it must be noticed that only one pair of anchor bolts can act at a time, and that the ultimate strength of this pair is about 55 000 lbs. per square inch, or 194 000 lbs. The area of the concrete at the ends of the bolts is 49 sq. ft., or, say, 7 000 sq. ins. If the tension be distributed uniformly over one-half of this area, the intensity will amount to less than 60 lbs., which is far below the ultimate tensile strength of even the poorest concrete.

Now, as to whether the rods are long enough to distribute their pull into the concrete, above the anchor casting, past experiments prove that they are amply so; but, even if they are not, the anchor plates will provide a proper distribution without overstraining the concrete.

It is, therefore, evident that there is no necessity whatsoever for carrying the rods any lower than they were carried.

In connection with the pedestals there remains but one point to be taken up, viz., whether the pedestals themselves have weight enough to resist the assumed overturning for which the anchor bolts were proportioned.

Mr. Waddell. In the worst case on the Loop, the point of flexure in the column of which is about 20 ft. above the bottom of the concrete, the base of the latter is 10 ft. square. Taking the center of moments at one edge of the base, the overturning moment is 200 000 foot-pounds. The total vertical load on the base is composed of the 40 000 lbs. of dead load on the column, the weight of concrete, which is about 66 000 lbs., and the weight of earth on top of the pedestal, which amounts to about 36 000 lbs., making a total load of 142 000 lbs.

If the resisting moment of the weight is limited to that existing when the intensity of pressure at one edge of the base reduces to zero, the lever arm of the resisting moment will be one-sixth of the width of base, or 1.666 ft., and the greatest resisting moment therefore will be 142 000 x 1.666 or about 236 000 foot-pounds.

It is therefore evident that, even if the earth about the pedestals were not tamped in, the pedestals are large enough to resist properly the overturning effect of the assumed thrust used in proportioning the anchor bolts.

As for the pedestals on the Northwestern Elevated, the conditions are quite different, the anchor bolts, of which there are but two per pedestal, being required primarily for the assumed transverse load of 600 lbs. per foot of span. If the length of the latter is taken as before at 50 ft., the total thrust is 30 000 lbs, or 7 500 lbs. per pedestal. The greatest unsupported length of column is about 16 ft., and, as both ends are fixed, the lever arm is 8 ft., making the overturning moment 60 000 foot-pounds. By assuming no train on the track of the column considered, the only load on the column will be the dead load, which amounts to about 32 000 lbs., and as its lever-arm is $7\frac{1}{2}$ ins., the resisting moment will amount to 20 000 foot-pounds, making the net overturning moment 40 000 foot-pounds, or 480 000 inch-pounds, for which the lever arm is 15 ins., and therefore the stress on the single rod 32 000 lbs., or a little over 18 000 lbs. per square inch.

The point of flexure in the column is 17 ft. above the base of the pedestal, thus making the overturning moment 127 500 foot-pounds.

The total load on the base of the 8-ft. square pedestal consists of 32 000 lbs. on the column, the weight of the concrete, amounting to about 48 000 lbs., and that of the earth above the pedestal, amounting to about 20 000 lbs., making a total load of 100 000 lbs., for which, as in the previous case, the lever arm is one-sixth of the length of the base, or 1.333 ft., making the greatest righting moment 133 000 foot-pounds, which is a little more than the overturning moment, showing, as before, that, even if the earth in the pits be not tamped, the pedestals are of ample size to resist properly the greatest overturning moment of the assumed loading.

It is therefore proved that all the adverse criticism of the design of the pedestals on both the Loop and the Northwestern Elevated is with-

out foundation, and that the consequent objections to these designs are purely imaginary. Mr. Waddell.

Mr. Seaman says, referring to the New York and Brooklyn structures:

"These elevated roads, after twenty years of service, under loads exceeding those for which they were designed, show no indication of such deterioration as would justify the prediction of the author that they will eventually be reconstructed because of their faulty details."

Perhaps Mr. Seaman will change his opinion about this after reading Mr. Hedrick's report. If on some of these structures 100 rivets per mile of double-track elevated road must be replaced each month by reason of their failure or working loose, as was stated to Mr. Hedrick, does it not show that the details are greatly overstrained and that the structure is in consequence gradually wearing out? The author's experience with ordinary railroad bridges of antiquated construction has been that, when such structures begin to fail in details, they sooner or later have to be taken out and replaced, in spite of all the patchwork that may be done on them.

Mr. Seaman asks for the details of the author's estimates, meaning probably the schedule prices adopted. The principal ones are as follows:

Metal erected and painted, $2\frac{1}{2}$ cents per pound; vulcanized timber in place, $38 per M., B. M.; rails with their details and fastenings in place, three 80-lb. rails per track, $1 80 per lineal foot per track; concrete, $7 per cubic yard; and excavation, including back-filling, 50 cents per cubic yard.

What metal is saved in Design 7 is required for end stiffeners and cover plates for cross-girders as compared with Design 6, thus making the weight of metal per lineal foot the same for both designs.

Design 8 is lighter than either of these designs on account of the greater simplicity of the horizontal bracing resulting from the abutting of the outer longitudinal girders against the columns, notwithstanding the "cross-girder strains and brackets," referred to by Mr. Seaman.

It would not be feasible in such a paper as this to give every detail of all the estimates made.

Answering Mr. Bouscaren's questions, the greatest variation in temperature was assumed to produce a variation in length of metalwork equal to 1 in. per 100 ft.; the wind load (or more strictly speaking the transverse horizontal load) assumed was 450 lbs. per lineal foot for the double-track structure, and 600 lbs. per lineal foot for the four-track structure; the speeds of trains assumed varied from 40 to 20 miles per hour according to the degree of the curvature; and all curves are compounded. The intensities of working stresses adopted in making the designs were as follows:

Flanges of longitudinal plate girders, extreme fiber, 8 000 lbs., allowing one-eighth of the web to act as a part of each flange; tension

Mr. Waddell. flanges of open-webbed, riveted longitudinal girders, 9 000 lbs.; compression flanges of same for combined bending and direct load, 9 000 lbs.; diagonals of same, from 6 000 to 8 000 lbs., according to the relative dimensions of angle legs; flanges of transverse girders, 9 000 lbs., allowing one-eighth of the web to act as a part of each flange; columns in compression only, $12\,000 - 45\frac{l}{r}$; columns for combined direct loads and bending of all kinds, including temperature effect, 20 000 lbs., where $l \div r$ does not exceed 45.

Mr. Horton points out that the author's elevation of base of rail is 21 ft., above the street. This applies only to the Loop, where various considerations necessitate a higher track level than that of the Northwestern, for which the height is from 18 to 19 ft. The height of the car floor was a fixed quantity, as it had to be made the same as on the other lines using the Loop.

Answering Mr. Mogensen's remarks concerning a solid floor, the author would state that the latter would not dispense with the use of timber ties, unless it involved great noise in operation; hence, Mr. Mogensen's first claim will not hold.

As an example of noisy operation in a structure where there is no timber cushion under the rails, the Park Avenue viaduct of the New York Central Railroad may be mentioned. On this structure the noise from a passing train sounds like that of an approaching tornado.

If Mr. Mogensen were to make a complete design for a structure with a solid floor that would be comparatively noiseless, he would probably find, as the author has found, that the extra cost would amount to much more than 15 per cent.

There was an error made in the preliminary edition of the paper in respect to the composition of granitoid, which has been corrected. Mr. Stuart's criticism, however, would now apply with still greater force, as the composition is less rich in cement than was stated. As it was Mr. Weston who specified and put in this granitoid, the author wrote him, sending a copy of Mr. Stuart's remarks, and has received the following in reply:

"Mr. Stuart's conclusions in respect to porosity of the mixture which we have used for the pedestal blocks on the Northwestern Elevated railroad are erroneous. The fact is that the texture of the finished stone is very compact and free from voids. The mixture, when properly manipulated, produces a stone which resists perfectly the action of frost.

"We have on the Northwestern Elevated road several thousand pedestals made from this mixture. These pedestals have been during the past winter exposed to temperatures of 20 degrees below zero. I have only recently examined personally nearly every pedestal on the line, and I failed to find one among them which gave any evidence of deterioration.

"As to the strength of the stones made from the mixture specified, they are superior in every respect to those made from the best lime-

stones mixed with sand and cement mortar. Furthermore, it is the mixture in common use in Chicago for the best grades of cement sidewalks and continuous curb and gutter construction. Hundreds of such walks and gutters can be seen in perfect condition after having resisted the elements and extraordinary traffic for more than ten years." Mr. Waddell.

The author must take issue with Mr. Trocon concerning the fixedness of column feet, for he is convinced that where four anchor bolts per pedestal are used on his Chicago work, the columns and pedestals are just as continuous as if the former were embedded in the latter to any depth.

The author agrees with Mr. Parsons in his preference for design No. 8. It is the most satisfactory of all the double-track designs figured upon, but, unfortunately, it could not be used on the Chicago work, as all the double-track portion of the structure is located in the street, where a spacing of 17 ft. between centers of columns is inadmissible.

Mr. Connor expresses his regret that facing the end angles of the longitudinal girders was not called for in the author's specifications. The specifications contained this clause:

"The ends of all webs that abut against other webs must be faced true and square or to exact bevel, and the end stiffeners must be placed perfectly flush with these planed ends, so as to afford proper bearing for the ends of the attaching girders."

In order to comply with these requirements the Union Bridge Company decided to make the end stiffeners $\frac{1}{2}$ in. thick and to plane the ends of the girders after the stiffeners were riveted on, while the Elmira Bridge Company chose to plane the webs first and then put on $\frac{3}{8}$-in. stiffeners to fit the planed webs exactly. The latter company, however, agreed to use thicker stiffeners and to rivet them on before planing, in case the inspectors reported the work to be unsatisfactory when done by the method last described. No complaint on this score has as yet been made, or, in truth, on account of any other matter concerning shopwork; and the author feels that he cannot speak too highly of the character of all the shopwork done thus far on his Chicago work by both the Union and Elmira Bridge Companies.

Mr. Hodge seems to think that the stating of correct principles of design for elevated railroads by the author is superfluous; but even to-day in designing structural metalwork these principles are more often honored in the breach than in the observance. As for "guessing" as to the number of extra rivets required for a connection, when the number required theoretically is small, the author maintains that two rivets do not make a proper connection except for lacing, and that when the number of rivets required by pure theory comes out almost exactly three or even four, it is better to add another rivet as a matter of precaution.

Mr. Waddell. The author agrees with Mr. Weston that, all things considered, it would have been better to place the top flanges of the longitudinal girders a little above those of the cross-girders instead of a little below. The result would certainly facilitate laying the track, but would require a little more metal and would involve a somewhat clumsy detail at the junction. On the connection of the Metropolitan Elevated to the Union Loop, which connection was designed by the author, such a detail was adopted at the request of the officers of the Metropolitan Company. In future work the author would not attempt to make the top flanges of consecutive longitudinal girders continuous or semi-continuous over the cross-girders; but would cut them square off so as to clear the top flanges of the latter, upon which he would place pieces of steel buckled plate to receive the ties.

The author is glad to see Mr. Lindenthal's remark about the separation of incoming and outgoing passengers. If he could have his own way on this question, the author would make this a *sine qua non* in designing all stations for elevated railroads. The Northwestern stations, as he designed them, certainly provide for such a separation; and it is to be hoped that they will be built that way, although there is now some talk of abandoning the exit stairways.

Mr. Lindenthal has failed to recognize the fact that there will be no side view of the four-track portion of the Northwestern Elevated possible except at street crossings, and that consequently the difference in depths of longitudinal girders at the braced towers can never be noticed; therefore it would have been a needless piece of extravagance to make the webs of the short girders as deep as those of the long ones.

In respect to the question of æsthetics there seems to be such a variety of opinion that the author concluded to consult several architects of established national reputation and leave to them the settlement thereof. He therefore wrote to Mr. Henry Van Brunt, of the firm of Van Brunt & Howe, Kansas City, Mo.; Mr. Chas. A. Cummings, of Boston, Mass., and Messrs. Carrère & Hastings, of New York City, asking them for criticisms of his designs.

Mr. Van Brunt replied as follows :

"You have asked me for a frank architectural criticism of your proposition to decorate the construction of an elevated railroad, as illustrated in the last pages of your paper presented to the American Society of Civil Engineers February 17th, 1897. The opportunity for the discussion of this difficult problem is so rare that I am disposed to avail myself of it seriously. The relations between our two professions are growing closer, and it is important that we should understand one another better.

"It has been observed that among semi-barbarous nations forms of art are developed from an instinctive conception of beauty, which has free expression because it is not embarrassed or sophisticated in its development by the knowledge of other forms of art indigenous to

other people and resulting from other conditions of material and use. Thus, among civilized nations the accumulation and organization of knowledge, which to every other form of intellectual activity is a stimulus, seems to have proved, at least to some part of the art of the 19th century, a positive impediment. The cultivation of the mind through the knowledge of past achievements has in fact rendered the architect of to-day so self-conscious, and has supplied him with such a multiplicity of conflicting ideals, that his inherent creative power is weakened and his natural initial force is lost in a sort of intellectual timidity and vacillation. With the distractions furnished by his familiarity with history he cannot adjust himself to his own environment with the frankness and *naïveté* by which the masters of classic and mediæval times developed architectural style. Mr. Waddell.

"In this respect the modern engineer enjoys a distinct advantage over his brother, the modern architect. Fortunately in the practice of his profession he is not embarrassed by these grave distinctions, and his art has consequently progressed with the general progress of the century. But when, in his bridge truss or his elevated railroad, he has evolved mathematically an economical structure, which commends itself to his own scientific judgment, and to the approval of those whose capital he is investing in a purely commercial undertaking, and finds at last that the results are an offence to the æsthetic instincts of mankind, the correction which he attempts to apply to satisfy this æsthetic instinct subjects him immediately to the very same embarrassments which beset the path of the architect. For almost invariably and inevitably this correction, as in the present case, is a reminiscence or tradition from an entirely different form of structure, and is applied too late in the process of construction to make good art. In fact, the correction is an afterthought; it is applied to a completed fabric, and forces it to assume an aspect which is not a harmonious development of its essential structure, but a concession to an arbitrary and conventional idea of beauty or grace.

"True architecture is construction carried to the highest point of development without the necessary addition of any elements foreign to its own conditions of stability and strength. Structure cannot be elevated into the domain of art merely by the application of ornaments. Ornament is contributory to a work of art and not essential to it. A Cistercian abbey has no ornament, but its rank as a work of art is as high as that of a Clunisian abbey which abounds in the richest decorative accessories. Certainly the true function of ornament is not to conceal or obscure construction, but to illustrate it.

"I very highly appreciate the motive which has prompted your attempt at decorated construction, and I recognize the ingenuity with which you have tried to solve this most difficult of all problems in design, but I beg to call your attention to the fact that this most praiseworthy effort would never have resulted as it has in your careful drawings if your mind had not been pre-occupied by the agreeable effect of the construction of a stone bridge. It is evident, however, that, executed, the phenomena of perspective would destroy this resemblance to this conventional type, and substitute some more or less unexpected and not entirely agreeable effects. It seems to me apparent, moreover, that the important arch form given to the longitudinal web is not an evolution from its essential structure, but is imposed upon it for the satisfaction of an ideal of grace; that the form of the brackets supporting the overhanging footway conceals, and certainly does not illustrate, the member which actually does the work; that the

Mr. Waddell. capitals and base moldings of the supporting piers are imposed upon a structure with which they have no sympathy, and are a reminiscence of forms invented for an entirely different material; and that the decorated entablature is merely a thin screen which does not suggest the structure which it masks, but recalls a structure of a very different sort, and is therefore with its moldings and panels simply a conventional and purely arbitrary symbol intended to agreeably beguile the spectator. You have done what a very large proportion of men in my own profession would have done, if called upon to make your completed construction more attractive to the eye, but all this decoration is applied and not inherent. It does not illustrate the essential and peculiar nature of the fabric and is not a part of it. Therefore, according to ethics of design, however agreeable and interesting to the eye, it is really a costly and ingenious deception and is not true art.

"If the structure without such masks is ungainly and uncompromising, the remedy to be sought for by the engineer should, it seems to me, be limited to bringing together the various members of a perfectly mathematical and economical construction with as much elegance of line and precision and finish of workmanship as he can possibly command. If he can use ornament, let him so use it as to illustrate the construction and not to conceal or weaken it. It is the misfortune of the engineer that he is dealing with a strictly mechanical problem, and is therefore constrained to use materials and methods which have as yet never been developed in the direction of that more perfect union which really constitutes the essential qualities of grace and beauty. I venture the proposition that, following the analogy of nature in the evolution of natural forms, no construction which is coarse or ugly can be perfect construction, and that the reasonable gratification of the educated eye must be the measure of such perfection.

"Centuries of experiment and study have been bestowed upon constructions in stone, baked clay, and wood, and certain ideals of beauty and fitness have been thereby developed suitable for such constructions. But the attempt to apply such ideals to constructions in iron or steel must result in error. The form which is beautiful and fit for the old materials will not necessarily be beautiful or fit for the new materials. Time and repeated experiments must determine the character of the new ideals by which we are to measure and judge the final perfection which apparently we have not yet reached in this department of human endeavor.

"We have all of us, architects and engineers alike, repeatedly committed the same faults which are evident in the interesting example which you represent. Therefore, the critic must present his strictures with becoming humility. I have simply stated the truth as I understand it, and I am very sure that your intelligence will receive it in good part."

Mr. Cummings' letter was as follows :

"I find the questions which you ask me rather difficult to answer categorically. I quite agree with you that as a rule the engineering structures which we are accustomed to see are unsightly and often hideous. I have in mind, at this moment, certain iron bridges in my own city, in prominent and most conspicuous positions, which are an offense to the eye and to the taste of thousands, so aggravated that I have often thought that every structure of the kind ought to be sub-

mitted to a competent commission for approval or rejection before being carried into execution. Mr. Waddell.

"Certainly an elevated railroad is generally an extreme instance of deformity, and every attempt to ameliorate its ugliness deserves to be welcomed and commended.

"Yet, if I am to speak frankly of the design concerning which you have asked my opinion, I must say that I do not feel that you have treated the subject in the best way. Your design would certainly conceal the rough features of the iron construction—the girders, the Z-bars, the struts, the rivet heads and the like—but the concealment is effected by covering them with an imitation of the forms of an architectural construction in stone, of which the decoration is drawn from classic examples. It is here that I conceive you to be working on a wrong theory.

"I do not believe in borrowing architectural forms and applying them to the service of an engineering construction. I have never seen an instance where such an application seemed to me successful; and fortunately such a violation of the principles of decoration is not necessary. Every species of construction is capable of being made comely if not actually beautiful, without any concealment or denial of its materials or its methods. If the great engineering structures have so far failed to bear out this assertion, it is because the engineers in the first instance, and in the second those for whom their structures are designed, have not yet felt the importance of making them attractive to the eye.

"It would perhaps be asking too much of a profession whose work is of so strenuous and practical a cast as that of the engineer that he shall receive the training of an architect in design, but I think it not only entirely practicable, but entirely desirable and important that our schools of engineering should take some account of the possibility of so treating a problem of construction, whether of steel or stone, as to remove as far as may be done the reproach of ugliness and coarseness from the great structures which are one of the most conspicuous and most characteristic features of our later civilization."

Messrs. Carrère and Hastings wrote:

"We beg to acknowledge the receipt of your letter of April 20th, with which you sent us extracts from a discussion on a paper which you read, treating of elevated railroads, and in which you ask for an expression of opinion.

"We feel very much complimented at being asked to advise you in this matter, treating, as it does, a subject which has always interested us very much.

"In general, engineering works do not aim at beauty, and we think that this is always a great misfortune—whether the work be important, as in the case of a municipal bridge, or whether it be trifling, as in the case of small railroad bridges. Any engineering work is a spot in the landscape, or in the city, which has either a good or bad influence on the general appearance of the panorama, and upon its enjoyment.

"The fact that the first aim of every work of engineering is practical, that the essential qualities are strength, simplicity, and economy of cost and of operation, lead many very able engineers to the conclusion that they fail in these qualities in the degree in which they may be artistic; and for this reason many of them are not only indifferent, but are opposed to having their work beautiful. This is probably due

Mr. Waddell. to a misapprehension on their part of the elements required to make such a work beautiful, and perhaps also, to the fact that the usual way of attempting this solution is so often irrational, and seldom, if ever, successful.

"It is, of course, a very desirable thing to consult a skilled architect as to matters of detail, such as ornamentation, the railing of a bridge, candelabras and other small details, which, if successfully designed, may add to the general interest of the bridge; but no amount of ornamentation can possibly add artistic interest to an engineering work unless the conception itself is artistic. In fact, ornament should be used very sparingly, and in an entirely subordinate manner.

"We believe that the great difficulty is due to the fact that engineers, not having been trained in matters of art, do not conceive or plan their structures artistically. They should seek the advice of the skilled architect at the very start, so that the entire work may be designed and constructed on artistic lines, which may even make the use of ornament absolutely unnecessary, or may make it of so little importance that it may be almost bad, and the structure still be beautiful.

"An iron structure, be it bridge, elevated railway or other, must be perfectly simple and rational in its construction; the material must always be used so as to express its individual character, and not try, either in its arrangement, proportions, or details, to assume to represent the use, proportions, or forms of another material; the columns should be only as big as necessary to carry the weight; the beams or girders only as big as necessary for the spans; and the ornamentation should be so designed as to be characteristic of the material and of the process through which it is obtained, whether cast, wrought or otherwise.

"In the case of an elevated railway, the conception is inartistic, as well as irrational. There is no logical or artistic reason for encumbering a street or avenue, or other highway, with a purely utilitarian structure such as an elevated railway. It destroys the outlook and the light, and in every possible way the enjoyment of the street or abutting property, as also the original purpose of the street; and it has no *raison d'etre*, excepting either the rapacity of the corporation which occupies the street in preference to buying its right of way, or perhaps the necessity for having it there as the lesser of two evils, whether ugly or not, where the right-of-way is not otherwise obtainable.

"The thing, therefore, that makes an elevated railway inartistic is the very conception of the idea, and not the execution of it. We do not believe that it would be judicious to have, as it were, a structure decorated throughout; but whatever is done to make an elevated railway more sightly will have to be accomplished by designing it in the simplest and most straightforward way, so that the purely utilitarian portion of it will seem as natural, simple and graceful as possible, and in contrast to the purely utilitarian mass of the structure, by devoting some attention to the frequently occurring stations, and, where possible, by breaking the monotony by an artistic treatment, such as a viaduct, or the introduction of masonry or other features which may lend interest to these particular spots.

"We sincerely hope that you will succeed in convincing your fellow engineers that they have just as much need of the co-operation of the skilled architect in all of their work of this character, as has the skilled architect of the co-operation of the engineer in his work. As

both works, that of the engineer and that of the architect, partake both of the useful, the true and the beautiful, it seems indispensable that there should be co-operation between the architect and the engineer and between the engineer and the architect, as the case may be." Mr. Waddell.

As the opinions of the three architectural authorities referred to are entirely in accord on the question submitted, there is nothing for the author to do but acquiesce gracefully in their decision and acknowledge that his design for "an elevated railroad for a large city where expense is no object and where appearance is the great desideratum" is not a success, but a violation of true art.

Far, however, from regretting that he introduced the design as a conclusion to his paper, the author is very glad indeed that he thought of so doing, for the reason that the remarks of the architectural authorities just quoted may have the effect of inducing engineers engaged in the designing of structural metalwork to pay in future more attention to the important question of architectural effect in their constructions.

The author desires to express here his hearty thanks to Messrs. Van Brunt, Cummings, and Carrère and Hastings for their courtesy in complying with his request to decide this question of æsthetics.

As Mr. Van Brunt points out, steel construction is a modern innovation, and consequently no attention worth mentioning has yet been paid to the development of artistic features in its designing, for engineers have been influenced mainly by utilitarian and economic motives. If the old ideals of grace and beauty that pertain to constructions in wood and stone are inapplicable to steel, it is now in order to establish new ideals that will apply thereto; and, as engineers in general have been too devoted to utility and economy to train themselves in the artistic, it would be eminently proper for some architect, who is posted in the designing of metalwork and cognizant of the fundamental principles which guide the structural engineer in his designs, and who is an authority upon æsthetics in his own line of construction, to make a special study of the subject of the architectural features of steel bridges, viaducts and elevated railroads, then write for the American Society of Civil Engineers an exhaustive paper thereon, from which and from the subsequent discussions could be established principles governing from an artistic point of view the designing of all classes of steel structures.

In bringing this *résumé* to a close, it is proper for the author to point out in what particulars he would change his plans and specifications for the Chicago elevated railroads in view of the criticisms made in the discussions, were the said plans and specifications to be redrawn.

First.—He would reduce the ultimate strength for basic medium steel 2 000 or perhaps even 3 000 lbs.

Mr. Waddell.

Second.—He would use carbon primer as the first coat of paint, and would endeavor to have it applied at the mills before the metal could be exposed to the weather.

Third.—He would consider very carefully and thoroughly the question of the advisability of omitting on tangents either the outer or the inner guard rails.

Fourth.—He would raise the top flanges of the longitudinal girders about 4 ins. above those of the cross-girders, and block up on the latter with buckled plates to receive the ties.

Appendix.—Data Relating to Vulcanized Timber.

"New York, April 4th, 1895.

"*Editor Railway World:*

"Dear Sir,—A year or so ago much attention was given by railway journals, people who have to do with maintenance of way, and inventors, to the matter of ties for the road-bed. Columns in papers and many pamphlets were filled with articles on metal and glass ties. Little or no attention was bestowed on the plain every-day timber which has always been with us.

"Recently nothing has been said of would-be substitute ties. Is this caused by the failure of the experiments with the substitutes, or is it that better results have been obtained from the timber?

"I am inclined to the latter belief, and in support of the same offer the experience we have had with track timber on the Manhattan elevated system in New York City.

"When constructed, the elevated roads were equipped with 5-in. x 6-in. x 8-ft. yellow pine ties planed on all sides. The timber was of the best quality obtainable. It was not long before we discovered the ties suffering from decay. To the surface railroad man this may appear strange, considering that our ties are laid on iron girders. We have, however, many peculiar conditions to confront, and the cost of tie renewals was a very serious item of expense.

"To find a remedy for this and reduce what was beginning to be an immense maintenance-of-way charge, many preservative processes were tried, but none seemed to do the work until vulcanizing the timber was used. This process was first tried ten years ago, when we put in two sections of 6-in. x 8-in. x 8-ft. ties; one section of vulcanized timber and the other section of untreated material. It was not a great while until decay began on the untreated ties, while those vulcanized are still in service as good as when first laid. * * *

"Respectfully yours,
"(Signed) R. Black, *Roadmaster.*"

The following are extracts from a report which is certified to by the same Mr. Black :

"Agreeable to appointment, Messrs. F. Holbein, F. M. Grumbacher and Daniel Meyers met Mr. R. Black, roadmaster of the Manhattan Railway, at his headquarters at South Ferry station, on May 3d, at 1 o'clock.

"Mr. Black, who has been with the road since 1869, called attention to half a tie, not vulcanized, that had been in use five years.

That portion of the tie where the rail had laid, and where iron bolts had been used, was very badly decayed, but the space between the rails showed no signs of decay. Mr. Black stated that vulcanized wood was not in the least affected by contact with the rail or bolts or metal surface, but that it seems proof against indentation by wear and friction, or pounding of the rail. Mr. Waddell.

"The party was then conducted over the line of the Third Avenue Elevated, in order to be shown a comparison between vulcanized and unvulcanized wood in actual use on the structure. The first stop was at Chatham Square Station, where special attention was called to the condition of the natural yellow pine laid in 1886 on both City Hall and South Ferry branches. It was very much decayed and some portions so soft that it could be pierced with the end of an umbrella. It was a very rainy day and the timber was thoroughly soaked. This timber, Mr. Black remarked, was being replaced as rapidly as possible with vulcanized wood.

"Our second stop was at the Grand Street Station, where vulcanized ties and guard rails laid in 1883 were examined. This vulcanized timber was found in as sound condition as when first laid. Mr. Black called attention especially to guard rails which he had bolted together in 1883, the inside rail vulcanized and the outside rail not vulcanized, in order to have both subject to precisely the same conditions in every particular, and to afford opportunity for comparison in later years. The vulcanized was as sound as when laid. The part not vulcanized was in a decayed, punky condition. Attention was called to the vulcanized flooring on the station platform. He stated that they formerly used tongued and grooved lumber, but now they used vulcanized slatting without tongue or groove, as it kept its place without warping or shrinking, although exposed to cold, rain and sun.

"The next examination was at One Hundred and Sixteenth Street. Ties not vulcanized, which were laid five years ago, were all being removed because of their decayed condition, and were being replaced by vulcanized ties."

* * * * * * * * * *

"Mr. Black stated that about four and one-half miles of creosoted ties were now in use on the suburban branch and called attention to the soft, spongy character of creosoted wood, that the iron plates supporting the ties were deeply imbedded in the wood, and that it was difficult to keep the spikes in place, especially on curves. Extra appliances had been used to keep the rail in place. He also stated that during the hot season, when the temperature changed during the day from 40° to 95° Fahrenheit, causing expansion of the rail, spikes near the center of the rail would be lifted out of place from creosoted ties. He also stated that these ties were of yellow pine and the very best quality of creosoting, but that their experience was such that no more creosoted timber would be used, as vulcanized timber gave much better satisfaction; besides it does not affect the hands and faces of the workmen who handle it as creosoted timber does."

The following is a copy of a letter directed to Colonel S. E. Haskin, under date of March 1st, 1889:

"In replying to your enquiries as to the life of the cross-ties and planking which has been treated by the vulcanizing process, which we placed on the structure six years ago this month, I have to say, timber is sound and the surface of the ties and planking very hard.

Mr. Waddell. "There are no indications of decay at the end of those planks which were vulcanized, while the planks not treated and placed on the structure about the same time are decayed at the ends, or where they are nailed to the supporting timbers.

"I am inclined to think the process of vulcanizing will soon be found to be the best way of preserving timber.

Very respectfully yours,

(Signed) Rob't I. Sloan, *Chief Engineer.*"

The following is a copy of a letter to the Haskin Wood Vulcanizing Company, under date of March 28th, 1891:

"In replying to your enquiry regarding my opinion upon your process of vulcanizing for the purpose of preserving wood from decay, etc., and especially with reference to the yellow pine railroad ties, which were treated by your company's process, and laid in the tracks of the switchyard of this company in the spring of 1884, having been in constant use and exposed to the full action of the elements, and subjected to extraordinary wear and tear, I have to say that, on the 6th day of March, 1891, I had two of said ties taken up for the purpose of making an examination of their condition, and was much surprised to find them in a perfect state of preservation, and practically as good as new ties, so far as wear was concerned, the spikes having held firmly, as they were originally driven.

"During my experience in the railroad business of over forty years, during which time I have used all kinds of timber in railroad work, and have tried the various kinds of treatment for the preservation of timber from decay, I am free to state that I have never found any method that has shown such a satisfactory result; and I believe your process of vulcanizing will increase the durability of timber at least 50 per cent.

"The remaining ties, which were treated by your company's process, are in the same place as they were first laid, and from present indications they seem good for seven years' more service.

"In conclusion, I would say that I think it would be to the interest of any company using timber, which is exposed to the elements, to at least give this process a trial, as they could not fail to be convinced of its effectiveness.

Yours respectfully,

(Signed) Rob't White, *Supervisor of Tracks and Repairs.*"

Mr. White wrote also to the same parties, under date of April 6th, 1891, as follows:

"Replying to your question as to the life of yellow pine ties, will say that, when used in the switchyard of this company, in their natural state, and exposed to the full action of the elements, they last, on an average, three years, during which time they have to be turned.

"The ties treated by your company's process of vulcanizing, and which were laid in the tracks of this yard in the spring of 1884, are perfectly sound, and have not been turned or respiked since they were laid."

The following is the *résumé* of a report to Colonel Samuel E. Haskin, under date of November 26th, 1894, by Mr. Alfred P. Trautwein, who had made a series of comparative tests on vulcanized and untreated yellow pine timber on the testing machines of the Stevens Institute, Hoboken.

Mr. Waddell.

"These experiments show the following average results.

"Modulus of rupture :	Untreated wood.....	10 762
" "	Vulcanized "	13 098
" elasticity :	Untreated "	877 098
" "	Vulcanized "	1 054 941

"These experiments, of course, were not numerous enough to determine exactly how much vulcanizing affects the wood, but they establish the general fact that so far from weakening the wood, the process of 'vulcanizing' seems to strengthen it ; the modulus of rupture by transverse stress being 21 per cent. higher. The crushing strength was increased 23 per cent.

The author has been informed that the Hon. B. F. Tracy, ex-Secretary of the Navy, with a view of adopting vulcanized wood in naval construction, appointed a special committee which visited the vulcanizing works in New York, and, after an exhaustive investigation, reported that vulcanizing increases the strength and durability of timber, and recommended that vulcanized yellow pine be used for backing in one of the monitors. Their tests showed that vulcanizing increases the strength of yellow pine 18%, and decreases the deflection over 13 per cent.

The following is a copy of a report to Mr. A. Bevier, General Manager New York Wood Vulcanizing Company, by J. A. Deghuee, Ph. D., Chief Chemist of the Pure Food Department of New York City, under date of January 29th, 1897 :

"As to the result of the various tests made of your vulcanizing process ; in order to condense it I will confine it to samples A and X. This will show you all the practical conditions of the changes brought about by your process.

"The piece of wood A was just twice the size originally of the piece I returned to you. The other half was cut up into fine shavings and the extractive matter dissolved out by cold ether, the contents being in bottle A. This piece of wood had been vulcanized by your process.

"Block marked X, untreated yellow pine, was also cut up and the extractive matter dissolved out by cold ether, contents being in bottle marked X. This block was also twice the size originally of the piece returned to you.

"The vulcanized extract in bottle A shows a mixture of resinous acids, together with a number of bodies similar to those in wood tar creosote, all of which have strongly antiseptic properties.

"By your process nothing escapes but the free water. The amount that can be extracted from the wood will vary in keeping with the character of it, *i. e.*, from a rich, resinous wood more can be extracted than from a lean porous wood. You will extract as much from vulcanized wood as can be extracted from untreated wood, nothing escaping in the process except water, and the amount will vary with the original condition of the wood. I do not believe that the strength of the wood is impaired in the least by your treatment; but on the contrary, the diffusion of the resins and other liquefiable matters throughout the wood, thereby adhering to the fiber, would

Mr. Waddell. have a tendency to solidify the contents and increase the strength. However, this is a mechanical question which can be determined by tests at Columbia College and Stevens Institute, where they have apparatus for making such tests.

"Besides the changing of the extractive matters into an antiseptic, you also coagulate the albumen, which has a tendency to seal up the pores.

"There is another benefit by your process which I think equally as important as the creating of an antiseptic and the coagulation of the albumen, and that is sterilizing the wood; and there is no doubt in my mind that from the amount of heat used, this is thoroughly done. In all wood there is living matter carried throughout it by the flow of sap; either living matter or spores which produce the same. This hatching, as you may term it, is brought about by heat and moisture and develops the spores into mould which eats the wood and produces what is known as dry rot. Decay is due to living matter and in order to produce decay in your process, the living matter will have to enter from the outside.

"By the creosoting process in some cases resin is mixed with the creosote to prevent solubility, and by your process I consider that you are accomplishing the same result. Your process also produces the same results to the very heart of the wood as are produced upon the surface. If the timber was of the quality of sample A, in my opinion you would create from 190 to 200 lbs. of antiseptic matter to a thousand feet board measure. I arrive at this conclusion from your statement that the average weight of yellow pine, such as sample A, is about 4 000 lbs. to a thousand feet board measure. The condition of the wood in your treatment would not be changed by the separating or splitting of the timber, as the treatment goes throughout, thereby leaving no exposed surface."

The author regrets the necessity for occupying so much of his *résumé* with testimonials as to the merits of vulcanized timber; but, as Mr. Belknap has asked for such data and tests, he cannot well avoid giving them.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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No. 807.

NOTES ON PORTLAND CEMENT CONCRETE.

By Andreas Lundteigen, Esq.

Presented April 7th, 1897.

WITH DISCUSSION.

A number of years ago the Society of German Portland Cement Manufacturers published an article claiming that good Portland cement could not be improved by admixtures. It seems likely that the purpose of that article must have been to counteract any endeavor by dishonest men to add poor admixtures, and thus lower the reputation of German Portland cement, which then had begun to invade the markets of the world. It is also possible that experiments with many cements made before that time would not show the advantage of fine silicious admixtures, as well as the present high-limed and high-testing cements. Besides it may also be that both good and valueless admixtures were treated under one head, and therefore condemned.

It is worth mentioning that although the use of hydraulic mortars is very old, and a thorough knowledge of the nature of setting and hardening is very important, it was not until recently that much

had been done in this line. Whenever failures in concrete works were reported, they were attributed either to poor workmanship in the construction or to bad cement, while in reality neither was the cause. A cement was regarded bad when it contained, through careless manufacture, too much free lime, magnesia or sulphuric acid. The harmful effect of free lime has always been well enough known, but there is at the present day, with improved machinery and methods of manufacture, no excuse for such free lime, and it is not often met with in practice. An amount of magnesia above 1½% was long regarded dangerous, and even to-day there are many specifications calling for a cement with less than 2% magnesia. The German manufacturers, to whom this magnesia question has been of most importance, have discussed it in their meetings and in their papers for a long time. The result is that to-day 3% of magnesia in Portland cement is thought harmless, and many claim that even 5% ought to be allowed. It seems to the author that this difference of opinion has resulted not so much from the different amounts of magnesia in the cement as from the excess, more or less, of basic constituents, such as lime, magnesia and alkalies. Sulphuric acid has been considered harmless in Portland cement only to the amount of 1 to 1½ per cent. A closer investigation of the effect of sulphates in concrete was first made by Messrs. Erdmenger, Candlot and Michaëlis.* The results are, in short, that the amounts of alumina play an important part, and that it is of material difference whether the sulphates are added before or after burning. If they are intimately mixed with the raw materials a considerable quantity may not only be allowed in the cement, but is beneficial.

The author does not believe that consumers run much risk from any of the previously mentioned causes of faulty cements, because there are very few cements that contain an excess of free lime, magnesia or sulphuric acid, and if such should be the case, ordinary tests in cold water would in a few days show the bad effects of sulphates, a simple analysis would give the amount of magnesia, and a 28 days' cold-water test or a few days in hot water would show the free lime. The principal danger in concrete construction has nothing to do with the above-mentioned causes, but comes from using high-grade, well-manufactured cements, in which an extreme fineness in the grinding of raw materials

* See *Thonindustrie Zeitung*, 1891, p. 925; and Candlot's work, entitled "Cements et Chaux Hydrauliques," 1891, pp. 243, 263.

and of the finished products together with a uniform, hard burning, enables the manufacturers to increase the amount of the basic elements to a maximum without getting an appreciable amount of free lime. Such a cement will, in a short time, obtain a very high degree of strength and give excellent satisfaction wherever used in air or away from the continual action of water. For such work it may take more sand and make a more durable concrete than the old-fashioned low-limed and coarsely ground cements. It is different, however, where the concrete is to be used under water, be it fresh or salt. Then high-limed, high-grade cements will not only prove inferior but dangerous, especially if the water is rich in sulphates,‡ as shown in Table No. 1.

TABLE No. 1.—Tensile Strength.

Cement Sample.	Pat Test.		Fineness. Residue on—		Neat Cement.					1 Cement to 4 Sand.				
	Cold.	Hot.	50 mesh.	100 mesh.	7 days.	28 days.	6 months.	1 year.	2 years.	7 days.	28 days.	6 months.	1 year.	2 years.
a	Good.	Good	1.0	6.0	528	731	752	797	854	133	160	249	263	185*
b	"	"	1.0	6.0	563	785	806	803	956	108	173	192	143*	000*
c	"	"	4.0	14.5	422	547	664	730	×51†	80	114	131	128	103*
d	"	"	6.5	19.5	528	692	730	752	813	90	119	172	151*	19*
e	"	"	2.5	18.0	396	572	740	795	774†	71	117	151	154	107*
f	"	Loose from glass	4.0	19.5	481	579	802	853	970	62	113	219	233	184
g	"	Good.	6.0	23.0	563	696	821	884	955	59	108	218	256	266
h	"	"	5.0	21.0	364	502	804	912	923	40	96	197	216	194
i	Surface scaled off	"	4.0	18.0	349	541	876	831	835	32	105	200	226	238

* These briquettes were cracked very much.
† " " " " at the corners.

Each of the tests in this table, with the exception of those for two years, is an average of five breakings. The two-year tests in this table and all the tests given in the remaining tables are each an average of three breakings. In order to make comparison easier, decimals have been omitted. The same sand was used for all the tests; it was passed through a 16-mesh and retained on a 20-mesh sieve. All briquettes were made by hand, and such amounts of water used as would give the best results with each individual cement.

The water used, both for gauging and immersion, was well water, containing in one liter:

‡ See also *Thonind. Zeitg.*, 1896, No. 25; article by Dr. Stutzer.

$Ca\,SO_4$, 1.0214 grams.
$Mg\,SO_4$, 0.2238 "
Na Cl, 0.1515 "

Samples *a*, *b* and *e* were German Portland cement, *c* was Belgian, and *d* English; *f*, *g*, *h* and *i* were samples of an American Portland cement. Samples *e* and *i* had been kept in the laboratory about 18 months, and were somewhat lumpy; the others seemed comparatively fresh and in the best condition.

It becomes apparent from an inspection of the sand tests in Table No. 1, that those briquettes which broke the highest in a short time fared worst in the long run, and analysis shows that those cements contain more basic elements, lime and magnesia, in proportion to acid elements, silica, alumina and oxide of iron, than the other samples.

It has long been evident to the author that under the hardening of cement mortar a part of the lime is continually set free or separated from its molecular combination with silica, alumina or iron; in other words, these last substances are able to combine with more lime and magnesia in a dehydrated state in the kilns than in a hydrated state in the mortar. Dr. Michaëlis* finds that about 33% of the hydrate of lime in the average Portland cement is set free and will seek other material to combine with. If reached by the air it will take up carbonic acid and form a carbonate, which does not injure the concrete; in pure water it will be washed away in the water, and the concrete will be left more porous and weaker; in sea-water, or water containing mineral salts, these salts will combine with the calcium hydrate and form voluminous double salts, which will swell and destroy the concrete. Mr. Gerhart Herfeldt discusses this same subject, and shows, like Dr. Michaëlis, how Portland cement can be improved by admixture of trass, but his tests cover somewhat too short a time to show the advantages of the admixture fully.

The author has often noticed that unwashed sand would give better tests than well washed and cleaned sand, and he can account for it only in this way, that the fine-clay substance in the sand is able to combine with the liberated lime-hydrate in the cement. It was this circumstance which first gave him the idea of improving concrete by adding a certain quantity of fine silicious materials; and experiments

* In an excellent article entitled "Das Verhalten des hydraulischen Bindemittel zum Meerwasser," published in *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1896, Nos. 6 and 7.

made subsequently more than satisfies him of the correctness of his first supposition. Out of many tests, more or less systematically carried on, the results of a few, which agree in everything with the others, are given in Tables Nos. 2 and 3.

TABLE No. 2.

	Neat cement.	1 part cement. 3 parts sand. water 12%.	1 part cement. 1 part sil. 3 parts sand. water 14%.
7 days	419	77	33
28 "	554	136	100
6 months	847	264	341
11 "	950	298	470
2 years			582

TABLE No. 3.

	Neat cement.	1 cement. 2,5 sand. water 12%	1 cement. 1 sil. 5 sand. water 12.8%
7 days	507	89	40
28 "	685	163	125
4 months	911	252	314
11 "	917	254	374

Table No. 4 shows the compression tests in pounds per square inch.

TABLE No. 4.—Compressive Strength, Pounds Per Square Inch.

	German Portland Cement.		American Portland Cement.	
	1 cement. 4 sand.	1 cement. 1 sil. 8 sand.	1 cement. 4 sand.	1 cement. 1 sil. 8 sand.
7 days	445	218	282	167
28 "	776	441	603	320
80 "	1 047	700	945	558
6 months	306	901	1 094	805
12 "	.....	1 518	1 403	1 409
1 day in air ..				
36 days " cold water				
10 " " boiler with pressure between 20 and 90 lbs	836	more than 2 030*	1 846	1 804

* The testing machine could break only as high as 2 030 lbs.

Table No. 5 shows the results of varying proportions of cement and silicious material. Cement *A* is American, and cement *G* is German, the same as *a* in Table No. 1.

TABLE No. 5.—Results of Varying the Proportions of the Ingredients.

	Neat Cement.		2 Cement. 1 Sil.	1 Cement. 1 Sil.		1 Cement. 2 Sil.	2 Cement. 6 Sand.		2 Cement. 1 Sil. 9 Sand.	1 Cement. 1 Sil. 6 Sand.		1 Cement 2 Sil. 9 Sand.
	A.	*G.*	*A.*	*A.*	*G.*	*A.*	A_1	G_1	*A.*	A_2	G_2	*A.*
7 days	464	566	233	95	147	42	129	185	55	27	52	Too poor to break.
28 "	601	800	284	154	243	84	183	223	115	92	92	76
80 "	....	....	.....	...	....	.....	248	215	181	151	131	141
6 months	....	....	513	373	504	262	293	294	256	213	218	175
12 "	882	891	683	546	613	474	366	287	414	422	415	404
							*436	*287	.....	*292	*305	

* 1 day in air; 10 days in cold water; 10 days in boiler with a pressure between 20 and 90 lbs. per inch.

Fig. 1 shows A_1, G_1, A_2 and G_2 graphically.

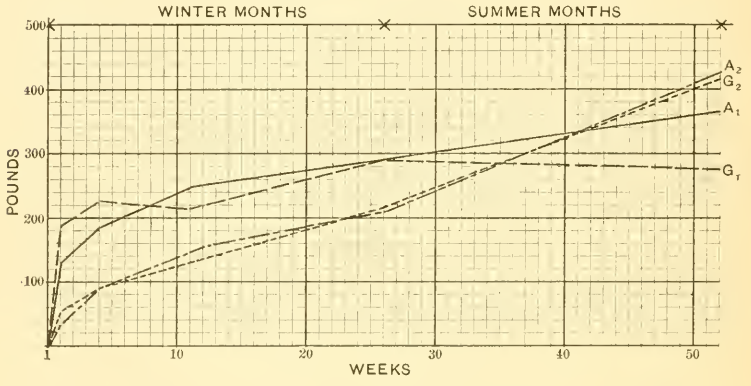

Fig. 1.

Such are the author's results invariably with silicious admixtures with Portland cements. What in the above experiments is called sil is a volcanic ash found in great quantities in Nebraska, Colorado, and other places. Its chemical composition is very similar to that of Santorin earth from Greece and trass from Germany. The analysis of the sample used for most of his experiments he found to be:

Silica	71.78
Titanic acid	0.80
Alumina	12.71
Oxide of iron	2.29
Magnesia	0.35
Lime	1.01
Water of composition	4.52
Alkalies (by difference)	6.54
	100.00

The composition varies, however, in the different localities and possibly at different depths in each deposit. Dr. Erdmenger found in a sample sent him from another locality:

Silica	74.28
Alumina and oxide of iron	13.80
Magnesia	Trace.
Lime	0.09
Oxide of sodium	1.87
" potassium	3.90
Loss by ignition	4.50
Undetermined residue	1.23
	99.67

Such ashes as contain the most chemically bound water are considered best for cement admixtures, although the author believes that in a long run there will not be much difference.

As a rule such ashes are found in layers from 5 to 10 ft. deep, but the author is told that in Colorado much thicker layers are found. In the banks it is somewhat moist and can be shoveled out easily; when dry, part of it will be lumpy, especially the more impure varieties. Squeezed out, it will have less than 1% residue on a 100-mesh sieve. The color is either gray or white, the gray being the cleanest, but coarsest. It is believed to originate from volcanic eruption; being carried by the wind, it would settle in small quiet lakes, which would fill up, solidify and afterwards be covered with dirt.

Such volcanic ashes and similar material, like trass and pozzolana, have been used with hydraulic limes for water mortars far back in history; thus Smeaton used them in the Eddystone Lighthouse in 1756–59. The author does not know, however, that they have been used to any extent with Portland cement.

Where such ashes, trass or pozzolana cannot be had at a reasonable price, other materials may be used. Waste products from alum factories and certain silicious slags are said to give very good results. Certain kinds of clay and sand when ground extremely fine will also give good satisfaction. It is the author's experience that sand and cement ground together (sand cement) will give higher tests in a short time than when the cement and sand are ground separately and mixed afterwards, but in a long-time test it does not seem to make any difference. How powerful such fine silicious material is in combining with

free lime can best be seen by adding increasing amounts of unslacked or partially slacked lime to Portland cement, and then making briquettes with and without the silicious admixture. Table No. 6 contains results of such tests, and Fig. 2 is a diagram of the same data.

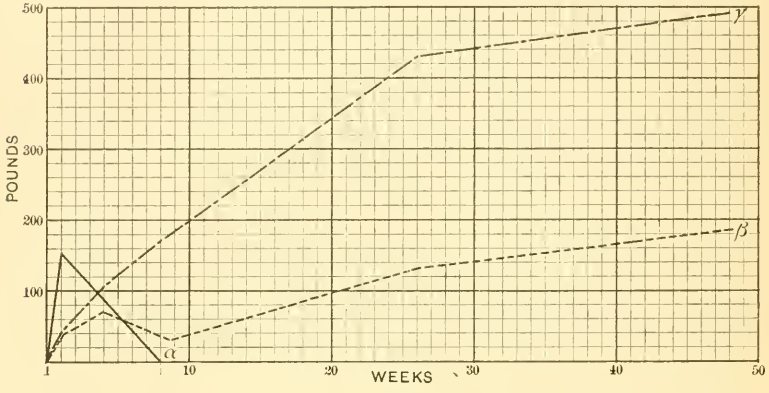

FIG. 2.

TABLE No. 6.

	1 cement. 0.5 partially slacked lime. 4 sand. α	1 cement. 0.5 partially slacked lime. 8 sand. 1 il. β	1 cement. 0.2 partially slacked lime. 6 sand. 1 sil. γ
7 days....	154	36	41
28 "	88	64	107
60 "	Fallen to pieces.	37	174
180 "	.....	132	435
330 "	.....	168	492

It is here specially interesting to study the middle column of the tests, β. It will be seen that while the destructive force of the free lime makes itself more and more prominent in the first 60 days, in which time the briquettes in column α are entirely destroyed, the briquettes column in β, while weakened somewhat, are able to regain strength and act like sound concrete, showing that the expansive force of the lime has been overcome. Column γ shows a steady and uniform increase, which indicates the perfect soundness of the concrete from the start.

DISCUSSION.

GEORGE W. TILLSON, M. Am. Soc. C. E.—The author states that all briquettes for the tests summarized in Table No. 1 were made by hand, and such amounts of water used as would give the best results with each individual cement. While engineers usually specify the maximum amount of water to be used in making briquettes, generally from 10% to 15%, according as the cements are tested neat or with sand, it is a fact that different cements require different amounts of water in order to bring out the full strength of each brand. It is perfectly well known, however, that it is impossible to prevent workmen from using an excess of water, no matter how careful the inspection may be. In making tests of cement for any particular work, the conditions should be nearly or quite the same as those under which the cement will be used, or each cement should be handled so as to bring out its maximum strength. It is unfair to classify cements according to the amount of water used in testing, when proportionately greater amounts may be used in the work. Hence the action of the author in using the amount of water which each brand of cement requires is particularly commendable. Mr. Tillson.

It will be seen in Table No. 1 that the greatest strength developed by any cement in the two-year neat tests was 970 lbs., while the same cement mixed with sand gave but 184 lbs. at the expiration of the same period, the lowest result of any of the samples which were perfect and almost the lowest of all those tested. The last sample in the table, which showed a low neat strength at the end of two years, had the second highest strength in the mortar at the end of that time. Experiments of a somewhat similar character were made by the speaker in a western city in order to establish a standard of the various cements used there. Soon after the tests were begun, the Board of Public Works and the speaker rejected for the coming year certain cements which had been used previously, and adopted others. The agents of the rejected brands appealed to the Common Council, and the latter began an investigation. The briquettes for the tests which were in progress at the time were made with such variable proportions of water as the tester had found adapted to bring out the greatest strength of each brand. The investigation began at the time of the breaking of briquettes ninety days old. The neat tests indicated that the rejected cements were stronger than those brands which were retained, and that their strength was increasing, but the mortar tests proved that the rejected cements were inferior when mixed with sand and decreasing steadily in strength. Subsequent experience with actual work confirmed the course taken in the matter and the result of the tests. It is evident that neat tests of unknown brands of cement are of doubtful utility in determining their actual value.

Mr. Goldmark. HENRY GOLDMARK, M. Am. Soc. C. E.—The subject of cement specifications, particularly the simplification of such specifications, is very important. In building bridge abutments and other concrete masses in which great strength was unnecessary, in the Rocky Mountain region, the speaker had to obtain his cement from San Francisco. It was carried by water to that port, and then shipped by rail about 1 000 miles to its destination. The matter of tests was important, because the cement could not be tested at the seaboard, and it was necessary to await its arrival on the work before examining it. The rejection of many carloads after such a long haul was a serious matter; fortunately the careful tests which were made gave good results. It required much consideration to determine on the course to be followed in case the results were not exactly in accord with the specifications, and it appeared wise to limit the orders to a few well-known brands which the engineers connected with the work had found entirely satisfactory and reliable after an experience of a number of years. It was found advantageous to retain in the concrete rock the small fragments of stone usually screened out; the material was of course well cleaned.

During the progress of the work some slag cements were sent to the engineers. Tests made with them indicated that they have a greater strength at the end of seven days than would be expected, but the increase in strength from seven to twenty-eight days was very small, and finally seemed to cease, and the strength to decrease, if anything. The speaker did not care to speak positively about this matter, as he was present during the beginning of the tests only.

Mr. Lesley. R. W. LESLEY, Assoc. Am. Soc. C. E.—The paper alludes to the danger of using high-limed Portland cements in salt water, and the necessity of adding a silicious material to the cement in order to enable it to resist such water. While Aspdin's patent on Portland cement was taken out in England in 1824, it was not until about 1840 that the manufacture became commercially successful there. This was followed by other works established in Germany and in Belgium a few years later. All of the original Portland cements were made with moderate percentages of lime, as compared with the percentages of silica and alumina, and for many years the manufacturers continued to produce cement in a perfectly safe manner, in order to obviate any danger that might arise from an excess of lime. Up to the time of the construction of the London main drainage works, the first undertaking in which great quantities of Portland cement were used, most requirements were satisfied by moderate results of neat tests made after seven days, and the two papers of Mr. John Grant,* show that with these moderate tests, excellent results were obtained up to very long periods.

For a number of years the manufacture of cement went on in the

* See *Proceedings* of the Institution of Civil Engineers, Vol. xxv, p. 66; Vol. xxxii, p. 266.

line indicated by the tests of Mr. Grant, but within the past ten years the requirements have been gradually changing, the tendency being to increase the fineness of the product on the one hand, and to increase the tensile strength of the neat cement at the end of seven days on the other hand. These two things, from the manufacturers' as well as from the engineers' point of view, are absolutely irreconcilable. The same Portland cement clinker, taken from the kiln and ground to a fineness of 90% on a 10 000-mesh sieve, will give a lower tensile strain in neat tests at seven days than if ground to a fineness of 75% to 80% on the same sieve. The obvious result of the tendency toward specifications requiring on the one hand very great fineness and requiring on the other hand very great tensile strength in neat tests, has been to lead the producers of cement toward the danger line, so far as the ultimate safety of the product is concerned. In order to accomplish the desired result indicated by the divergent elements of these latter specifications, the proportion of lime in the cement was increased 3% or 4%, a process just as simple as adding more clay to the material to run it up in the elements of silica and alumina, and costing the manufacturer no more. The cement was then ground very fine and passed all the specified tests. Meanwhile, however, specifications were still being raised, and the irreconcilable elements of seven-day neat tests and extraordinary fine grinding still further increased. This entailed still higher lime, and the discovery was made that this overlimed Portland cement would sometimes crack at short periods, and sometimes go to pieces at long periods. To meet this condition of affairs, which certain engineers alleged ordinary cold-water tests were unable to detect, many new tests were proposed, such as boiling, hot water, hot air, steaming and other similar violent methods, which it was claimed would discover the presence of an excess of free lime. Then the manufacturers were forced to devise some method of satisfying these three conflicting requirements. Gypsum or sulphate of lime in its crude or calcined condition is about as cheap as most of the materials, which, in the ordinary course of manufacture, ought to enter into cement, and it was soon found that when a small percentage of this material was added to the cement after calcination, that the fineness, the high seven-day neat test, and the boiling test could be easily met, and by tables which the speaker had occasion to refer to before this Society some years ago,* it was shown distinctly that every cement which was high in sulphuric acid and high in lime, passed the boiling tests and the other requirements of the high specifications. The outcome is that a man as distinguished as Dr. Michaëlis, in his recent writing on the subject, finds that cements laid in sea water prior to the increase in neat tests stood and are still standing without a complaint against them. Of late years, however, there has been the

Mr. Lesley.

* See *Transactions*, Vol. xxxii. p. 332.

Mr. Lesley. failure of the Aberdeen Docks, as well as similar failures of sea works laid in Portland cement, to which he refers. In reply to Dr. Michaëlis, the German Society of Portland Cement Manufacturers cites in support of the fact that Portland cement does endure in salt water, works laid as far back as 1840, where the character of the cement was very different from the character of the Portland cement made to meet the abnormally high neat specifications of the present day.

Broadly speaking, therefore, the recent failures of Portland cement in salt water were due to no defect in cement unknown to the men who first made the material, but were due to recent specifications and requirements absolutely beyond any strain that would be put upon cement. The results of the work executed in sea water within the last ten years and criticised by Dr. Michaëlis are precisely those which the people who have interest in the successful manufacture, introduction and use of Portland cement for all kinds and all character of work are compelled to disown absolutely.

The high and conflicting requirements have, to the speaker's mind, produced a condition of disease, and it would seem to him that had the author proposed a return to old methods of manufacture, old modes and kinds of tests, and to the old and well-established landmarks, he would have accomplished a more permanent result than by temporizing with the matter by adding sil or other infusorial earth to overcome a condition that should never have existed.

Trass, as proposed by Dr. Michaëlis, and sil, as suggested by the author, are not the only materials which, when ground with cement or mixed with it in a powdered condition, improve it and increase its temporary strength. At Malta, a series of tests by British army engineers show the addition of ground limestone to give better results than ground granite, and at Lafayette College some recent experiments by students there show similar results by the addition of fine screened dolomitic limestone to concrete. In these last experiments it was also indicated that in making concrete without separating the dolomitic limestone screenings from the broken stone, the concrete was stronger than when sand, clean stone and cement were mixed together.

The author states that he mixes the silicious material, stone and cement with 14% of water. The silicious material, commonly called infusorial earth, has the following composition:

Soluble silica	75.97%
Alumina	2.37%

Some experiments were made by Frederick H. Lewis, M. Am. Soc. C. E., with this material, and the following results were obtained.

When dry, 300% of water is needed to mix it neat. When mixed 100 cement to 40 infusorial earth, the mixture takes 100% of water to make briquettes, while the ordinary Portland cement takes only 22%

of water. When mixed, 100 cement to 40 infusorial earth to 420 sand, 30 parts of water are required. Mr. Lesley.

	Weight.	Tensile strength.
Neat cement mixture	160 grams.	650 pounds.
Cement, 100; infusorial earth, 40	62 "	52 "
3 Sand to 1 cement	138 "	240 "
42 Sand, 10 cement, 4 infusorial earth	108 "	40* "

The result of this would indicate that if infusorial earth was used and represents the sil referred to by the author, his percentages of water differ materially from those obtained by Mr. Lewis.

The main point that the speaker desired to make in summing up is that if manufacturers were not forced to meet very high and conflicting requirements, engineers would use the same grade of cement that has won the confidence of everybody, and led people to consider concrete as good as stone, it would be a much simpler matter to continue furnishing the same cement, and retain its high character, than it is under some of the more recent specifications.

Large quantities of slag cement, mentioned by Mr. Goldmark, were made in Germany about 1885. Investigations of the process and the product in this country had much the same results as he mentioned; the results of long-time tests were failures. A United States Consular Report† states that out of about fifty slag cement works in Germany in 1890, only two were then in operation, from which fact the growth of the industry in America can be predicted. The chemical difficulty of the process is the presence of sulphides in slags, and until some reliable method of dealing with them is devised, no good uniform slag cement will be made. The practical difficulty is that no one making first-class iron or steel will lay much weight on the kind of slag he is turning out, and Portland cement is too important in its uses to be dependent for its manufacture upon the production of a uniform by-product of another industry.

* Seven days.

† Dated July 3d, 1895.

CORRESPONDENCE.

Mr. Maclay. W. W. MACLAY, M. Soc. C. E.—The paper does not make out a case against using high-grade Portland cements, which of late years have come so much into favor. The question of mixing various materials with Portland cements, both for the purpose of cheapening and also of improving them, is quite an old one, as the paper states, and has been much agitated, both in this country and abroad; but up to the present time, as the German manufacturers very justly claim, no commercial substance has been discovered, which, mixed with Portland cement, improves its strength, both in air and in water. The most that can be claimed as proved is that certain substances can be mixed with Portland cement, which cheapen it without seriously diminishing its strength, especially in the sand mixtures. This is especially true of sand or silica cement, where the sand mixtures are almost as strong as the parent Portland cement from which the silica cement was derived.

The distinction is not brought out in the paper, between mixing an additional substance with Portland cement, so that one portion of the cement is replaced by another material, and simply making an addition to Portland cement mortar. The German manufacturers say, if Portland cement is replaced by any other substance, the strength of the resulting mortars is diminished; this is also the writer's experience. On the other hand, if finely pulverized substances, such as silica, be added to a true Portland cement mortar, they may by filling up the voids, especially in the case of lean mortars like one part cement to four parts sand, cause an increase of strength. This is really a physical improvement of the mortar, and has nothing to do with the question of free lime in the Portland cement itself.

In the table it is not stated that the tests were made on briquettes immersed in water, except in conjunction with boiler pressure tests. The inference is they have been immersed, and it would be interesting to know the author's experience with mixtures of sil kept in air.

Several years ago the writer conducted an extended series of tests with trass and pozzolana mixtures, as compared with Portland mortars. The former substances are very nearly like sil in chemical composition and in the following respects:

If added to neat Portland cement, they do not improve it. If added to Portland cement mortars, they have a weakening effect at first by reason of their extreme slowness in setting, but after long periods they add strength. For instance, Table No. 5 shows that the addition of one part of sil to one part Portland cement diminishes the strength of the neat cement at 7 days to about one-fourth that of the original cement, at 28 days to about three-tenths, and at one year to about three-fourths. The same table shows that by adding one part of sil to a Portland

cement mortar of two parts cement and six parts sand, the strength of the mortar is diminished until the end of one year, when it begins to increase. In the present time, when buildings and engineering works are carried to completion so rapidly, can engineers afford to add anything to Portland cement to diminish its first strength, with the hope that in a year or two it may improve it? Mr. Maclay.

The great advantage of using a high-grade Portland cement for water work is it gets its strength so quickly that it does not experience the disintegrating effect weaker mortars suffer, and the writer cannot but think this strength is permanent.

In view of the good results of Portland cement in actual practice, engineers cannot accept too cautiously the criticisms of theoretical tests, especially when extended over long periods where liability to error is greatly multiplied. For example, the sea fortifications of Copenhagen have been built forty years and are to-day in a good state of preservation; there a Portland cement with nearly 65% of lime was used.

JOHN F. WARD, M. Am. Soc. C. E.—The reports of tests of cement, as given in this paper, are interesting as showing how very small is the reliance which can be placed on the results of short-time experiments as to the tensile strength of the cements now in general use. Table No. 1 shows that of nine samples of neat cement, the best, as shown by two years' experience, held only fifth place in the list at the end of the first seven days, being nearly 15% weaker than the cement which at that time seemed to be the best, but at the end of two years the fifth in the list rose to be first, thus proving, in this case at least, that the seven days' test was not only useless, but in a high degree misleading. Mr. Ward.

In the mortar tests in the same table the discrepancies are even greater between the short and long-time experiments, as the cement which at two years proved to be the best, at seven days was seventh in a list of nine, and one which was at the head of the list in twenty-eight days fell to the foot in two years.

The tendency for some seasons past has been to question the entire reliability of short-time tests as a guide to all of the good points of cement, and such a showing as is made in this little table ought to make any one think whether it is worth from 20% to 50% of the cost of a barrel of cement to find out what it will do in the way of hardening in a week or even in a month, when, as would appear from the results shown, that the information so obtained may be of no use whatever.

It seems rather odd to see the engineers, who are supposed to be on the lookout for deficiencies, following the lead of the manufacturers in using the most expensive apparatus and the greatest care to coax the specimens to behave well by setting up in a week, and giv-

Mr. Ward. ing a showing which the experience of a year or two may turn to ridicule.

The reason why the short-time test is so fallacious is that it is simply a record of the strength of the hydration, which is merely a temporary crystallization or solidifying of the water in the mixture, whereas the ultimate strength of the cement, which is often double that of the hydration period, comes in the shape of silicification, which is a far more perfect and permanent combination, but requires more time for its completion.

Many engineers will say that the needs of their work will not allow them even a week's time for testing their cement, but this only emphasizes the objection to short-time tests, and adds more reason to the call for something which may take the place of the common tensile breaking of briquettes.

The question comes then, in what direction to look for relief. One obvious way is to buy on reputation almost entirely, and the German manufacturers have worked hard and faithfully in this direction with such success that very large quantities of their cement are used by parties who have faith in their very elaborate and costly laboratory tests, without anything more than the slightest examination of the quality by the buyer. There are also in this country many makers whose product has been for years so uniform and well known that the engineer feels at his ease in using it, even if he is not so situated that he can make thorough tests of his own, and wait a year or two to see the results.

It seems to be the almost universal opinion that the disastrous going back of cements from their flattering short-time tests is caused by the presence of lime in a free state, or in such form as to be set free by the action of the other ingredients under the conditions to which they become exposed in use. Some authorities say that this excess of lime can be detected by tasting; but, whether this is correct or not, it would be very desirable to find some chemical reagents which, applied to minute quantities of cement, would show by change of color, ebullition or otherwise, the presence of the matter which, in the long run, would make the mortar return to the shape of loose powder.

Mr. Michaëlis. Dr. W. Michaëlis.—It gives the writer the greatest satisfaction to learn that the author has found and drawn attention to an American pozzolana, apparently identical with Santorin earth, which is also a volcanic ash, or granulated trachyte-porphyry, or triturated pumice stone After trass, Santorin earth is the best admixture for sea mortar; it contains about 80% of hydraulic substance, and at least 60% of hydraulic silica. Such a pozzolana, dried and sifted, or ground and sifted through a No. 80 sieve, will undoubtedly make an excellent mortar in combination with high-class Portland cements and hydraulic

limes. The writer would advise a mixture of six-tenths, by weight, of Portland cement and four-tenths of the sil, although the latter will give a remarkable mortar if used in the following combination : Mr. Michaëlis.

4	parts	by weight or	3	by	volume	of pozzolana.
1	"	"	1	"	"	quicklime paste or powder of hydrate of lime.
1.5	"	"	0.5	"	"	sand.

Such a mortar contains only about one-fourth of the lime in Portland cement mortar, and is the best known at present for resisting the action of sea water. It hardens very slowly, especially at low temperatures, and if left for three or four days—even seven will not do harm—until it begins to set, it may be dropped into deep water without any danger of being washed out.

The writer recommends a mortar of Portland cement to secure the strength of this material, and enough pozzolana, rich in hydraulic silica, to bind the excess of lime which becomes free during the hardening of the cement. He would also advise American engineers to try the sil discovered by the author in the following combinations :

First.—With the best Portland cement and a low percentage of alumina.

Second.—With strong hydraulic limes.

Third.—Mixed with quicklime, as previously indicated, in strong mortar-mills. The concrete made with this mortar should have 16 parts, by volume, of broken stone, 15 parts of sil, 5 parts of quicklime paste or powder of hydrate of lime, and 2 to 3 parts of sand.

Richard L. Humphrey, Assoc. M. Am. Soc. C. E.—The paper appears to the writer to lack important detail information and data sufficient to confirm the theories advanced. Mr. Humphrey.

Concrete is defined as a mixture of two parts, the mortar of cement or lime and sand, and the aggregate, broken stone, crushed slag, gravel, etc. While admitting that mortar is the essential part of concrete, the writer is not willing to apply to concrete deductions based on mortar tests alone. In the tabulated tests in the paper it will be observed that the compositions are exclusively sand and cement.

The author states that "it becomes apparent from an inspection of the sand tests in Table No. 1, that those briquettes which broke the highest in a short time fared worst in the long run, and analysis shows that those cements contain more basic elements, lime and magnesia, in proportion to the acid elements, silica, alumina and oxide of iron, than the other samples," yet he does not present these analyses to confirm the statement. Again, in the analysis of the well water he neglects to state whether the water had an acid or alkaline reaction, which is a very important factor in considering the probable action of the salts contained in water acting on masses of cement.

The author also fails to describe the sand used in making the tests. He does not state its mineralogical nature ; whether it was a

Mr. Humphrey. natural sand or a standard crushed quartz sand. If it was a natural sand, it is important to know whether it was a bank or a bar sand, and whether it was washed and freed from any foreign matter it may have contained before being used.

On inspection of Table No. 1, it will be noticed that there are but two of the samples which do not show a decrease in strength in the two-year tests, and it is interesting to notice that both of these cements are American brands. It has occurred to the writer that possibly the sand used in these tests may have been the cause of this decided decrease in strength. It has been his experience that where the basic elements are in excess in cement the neat tests are the first to show signs of unsoundness. In Table No. 1 it will be observed that only the sand tests show a loss of strength, and this fact seems to cast suspicion on the character of the sand used.

The writer has also found that where swelling takes place in cements, the neat briquettes, being more compact than the sand briquettes, and therefore having fewer voids, show this action more strongly. It is still less noticeable in concrete.

TABLE No. 7.—Rearrangement of Table No. 1.

Group.	Fineness. Residue on.		Neat Cement.					1 Cement ; 4 Sand.				
	50	100	7 Das.	28 Das.	6 Mos.	1 Yr.	2 Yrs.	7 Das.	28 Das.	6 Mos.	1 Yr.	2 Yrs.
American	4.8	20.4	439	580	826	870	921	48	106	209	244	221
Belgian	4.0	14 5	422	457	664	730	851	80	114	131	128	103
English	6.5	19.5	528	692	730	752	813	90	119	172	151	19
German	1.5	10 0	496	696	766	798	862	106	150	197	187	97

The writer has arranged in Table No. 7 the tests given in Table No. 1 in groups according to the country in which the cement was manufactured, and it will be noticed that the average English Portland makes the poorest showing, the American Portland the best, and Belgian and German next. The writer has found that English cements, as a rule, are low in lime and magnesia, while American, Belgian and German cements are higher. As the analyses of the cements from which the tests in Table No. 1 were made are not given, it is impossible to carry the comparison further. It will again be noticed that the average neat tests show a uniform increase, while the sand tests show a decrease in strength at the end of one or two years.

The author has stated that the mortars which yield high tests for short periods of time showed the greatest decrease in the long time. It will be noticed on comparing the average sand tests of the English

cements with those of the German cements, that the English, while giving lower tests for short periods of time, show the greatest decrease in the long run. Mr. Humphrey.

The author does not state whether the water used for the tests recorded in Tables Nos. 2, 3 and 4 was the same as that used for those in Table No. 1. If such is the case, then the tests in those tables do not confirm the conclusions drawn from Table No. 1, as none of the tests in Tables Nos. 2, 3 and 4 show a decrease in strength.

Again, in Table No. 5, the cement marked *G* is stated to be the same as sample *a* in Table No 1. It will be noticed that there is 100 lbs. variation in the neat tests at the end of one year.

The question naturally arises, whether the tests were all made at the same time, under the same conditions and by the same person. If so, then the variation shows a decided lack of skill in making the briquettes, and that the number of briquettes were too few for obtaining a fair average.

The author infers that the addition of sil, a soluble silica, to a cement high in lime, not only prevents the tendency to lose its strength, but on the contrary produces a decided increase of strength, and then he quotes Tables Nos. 2, 3, 4 and 5 in support of this statement. Yet, on comparing the last column of Table No. 5, with the column headed A_2, it will be found, as might be expected, that the additional part of sil decreases the strength of the mortar appreciably.

It will be noticed that this sil is exceedingly fine, having a residue of only 1% on a 100-mesh sieve. It seems to the writer that this fine sil merely fills the voids of the coarser sand, and that the mixture being more dense is therefore stronger, just as a concrete made of stone of graded sizes is more compact and often stronger than one having stone of the same size.

Frederick H. Lewis, M. Am. Soc. C. E.—The paper presents a question which has already been debated for fifteen years in Europe, and is now scheduled by a German commission for a series of experiments covering a still longer term. This question is whether or not Portland cement may be ameliorated by the addition of substances containing hydraulic (or soluble) silica, and it is interesting because by general consent the theory is conceded to be correct by those who declare it mischievous in practice. Mr. Lewis.

As the author's general presentation of the subject is meager and his co-ordination of the results reported with previous work somewhat unsatisfactory, a brief outline of the main argument as it now stands may be of interest, and to this the writer addresses himself.

In the opening paragraph the author writes: "A number of years ago the Society of German Portland Cement Manufacturers published an article claiming that good Portland cement could not be improved by admixtures." While the reference is not explicit, there can be

Mr. Lewis. little doubt that he has in mind the communication of the German association to the Prussian Minister of Public Works in 1882. This reads as follows:

"Normal Portland cements do not require a so-called improving addition; such an addition produces rather a decrease of strength which is nearly proportionate to the amount of the addition"; and further, "The Council is unfortunately of the opinion that the means of coercion which the factories, desiring to furnish for the future an unadulterated article, have at hand, are not sufficient effectively to hold in check these improper practices, and the more so that the desire for gain, which here forms the only motive, does not even disdain to cover itself with the mantle of pretended science."

This harsh criticism was directed at Dr. William Michaëlis, of Berlin, and was so accepted by him. It appears just as quoted in his latest pamphlet defending this theory.* His original statement of the theory in 1882 read as follows:

"When Portland cement is gauged with water, and, in consequence, hardens, a certain arrangement of the molecules takes place during, and as a result of, the absorption of the water. In the alkaline water which at once forms in the cement—many cements contain free alkali, and are in consequence quick setting—calcium hydrate separates out in a crystalline form; indeed, in the course of the hardening process, about a third of the whole quantity of lime present in the cement acts thus. The lime thus separated in crystals has very little binding action, it has rather a tendency to destroy the cohesion which the cement mass has already attained. This, however, cannot happen in good cements, because the cohesion is already too strong, and the separation of the lime takes place too gradually.

"After such a consideration of the case, it may be concluded *a priori* that if there are offered to the lime, while it is in process of separating out, pozzolanas (*i. e.*, substances which, in combination with calcium hydrate form cement), the amount of effective cement in the mortar may be increased in such a way that no more caustic lime can be deposited in crystals, but that the entire quantity of calcium hydrate becoming liberated, and which must first go into solution before it can crystallize, is employed in the formation of calcium hydrosilicate (and aluminate)."

His fuller presentation of his views in the pamphlet of 1895 before referred to reads thus:

"From this it was but a step to the conclusion that the improvement, by means of additions containing hydraulic silica, of hydraulic cements with an excess of lime must be of the very greatest importance and applicability in the case of mortars which have to be exposed to the action of sea water, because the study of the behavior of these mortars led me to the conviction that the free lime is the chief cause of the frequent failure and rapid destruction of hydraulic mortars in marine construction.

"By means of appropriate additions, the whole of the excess of lime could be securely combined, and the mortar thereby converted into one very much less capable of reaction; this would then inevitably be shown very soon and very distinctly, not merely in the degree of

* "The Behaviour of Hydraulic Cements in Sea Water," Berlin, 1895.

durability, but in the strength. Thus the behavior of the mixed hydrau- Mr. Lewis.
lic cement in sea water could not but form the truest touchstone for my theory, and also be of the highest importance from the point of view of national economy."

"My present proposal goes at once to the root of the evil by laying hold at the outset of the injurious excess of lime, and converting it to a useful purpose; this proposal is based upon the fact which I have long upheld, that clinkered Portland cements, too high in calcic oxide and hydraulic limes, may—either in the process of manufacture or in the preparation of the mortar—be improved, and more especially rendered more capable of withstanding the decomposing action of sea water, by means of such additions as will go to form fresh hydraulic mortar with the excess of lime or with that which is set free during the hardening process, *i. e.*, with pozzolanas in the widest sense of the word. Such suitable pozzolanas are hydraulic silica itself, opal, infusorial earth, pozzolanas in the more restricted sense, trass, Santorin earth; also further, powdered glass, certain granulated blast-furnace slags, burnt alum-shale, kaolin, brick-dust, etc.

"Of all known additions of this kind, the most effective is real trass on account of the high proportion it contains of the hydraulic factors, and of the excellent quality of that portion of it which acts as sand."

Right or wrong then, whatever credit attaches to this theory of ameliorating cements belongs to Dr. Michaëlis, who since 1882 has borne the brunt of severe criticism, personal as well as technical, for the views he holds.

The strongest denials of these views have been by the German society and by M. Candlot, the well-known French authority. The reply of the German society appeared* with a note stating that it definitely closed the question. Omitting the first half of this document, the main argument reads as follows:

"It is impossible to oppose to these proofs the cases in which Portland cement has not been satisfactory in the sea. We must conclude that in these special cases there have been employed mortars which are too meager and in consequence are porous and of insufficient strength, or else that the work has been badly executed. It is certain that Portland cement cannot be held responsible for such faults.

"The Society of German Portland Cement Manufacturers has endeavored for a long time to observe the strength of limes and of cements in sea water, to enlighten its belief in this respect. At its request, and from the conviction that only tests made in the sea were capable of giving useful information, the Prussian Minister of Public Works charged the Royal Administration of the Island of Sylt with these tests. The cost was borne partly by the Ministry and partly by the association which sent besides to the Island of Sylt a commission chosen from its members. The observations were made especially on rich mortars which by reason of great strength and impermeability cause them to be less influenced than the others by mechanical effects. These tests are not yet terminated. As regards cement mortars, however, it is a fact that all the samples plunged in sea water which are

* In the *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1895.

Mr. Lewis. under observation are up to the present time absolutely intact and are acquiring an increasing resistance; although, as has been remarked above, the resistance of Portland cements may be somewhat less in sea water than in fresh water. As to mixed mortars of Portland cement and lime, and especially to the mixtures of trass and lime, they are attacked by sea water.

"Michaëlis recommends the addition of trass to Portland cement intended for maritime constructions in order to render it more resistant to sea water, with the idea that the lime rendered free by the setting of cement will combine with the silica and alumina of the trass forming thus a stable compound in the presence of sea water. He has established a series of tests and obtained by the aid of an addition of trass to cement mortar a considerable increase of strength. We desire to draw attention to this fact that there is reason for distinguishing between the case in which Portland cement is mixed with another substance (in such a way that a part of the cement is replaced by an equal part of this other substance) from that in which a mortar of Portland cement and sand is completed by the addition of another substance. If the cement is replaced partially by other substances, the preceding table relative to hardening in sea water shows that the resistance is diminished, except in case of the addition of ultramarine and other substances producing analogous effects.

"If on the contrary fine powders of hydrated lime and sand within certain limits are added to cement mortar, these do produce an augmentation of strength in consequence of the filling up of the voids in a meager mortar. It is not, then, a question of the amelioration of the cement, but of the amelioration of the mortar. Trass, at the time of hardening in water, produces a more intense effect than other substances, because at the same time that it fills the voids it causes a new augmentation of density by combining with the hydrate of lime which is placed at liberty in the cement. But rich mortars which contain few voids are not ameliorated by such additions. Trass itself does not produce any improvement in them in despite of its richness in active silicic acid, because these mortars lose density by the avidity of trass for water, and the trass is unable to produce a better union of the elements of the mortar.

"In order to demonstrate the effect of pozzolana in the hardening of Portland cement, we have made some tests with trass, which is a most active pozzolana, and as Michaëlis has done, we have added the trass to cement mortar. For these tests, as the Maritime Commission of the International Congress has decided, we have especially chosen rich cements since these are to be recommended for works in the sea because of their strength and hardness; their density gives them better protection from the attacks of the sea. We have experimented in the same way nevertheless with a meager mortar, one to four. For these tests we have used sea water from the North Sea, for the reason that sulphates in solution (as the tests of Michaëlis have shown) act in a manner quite different from sea water either natural or artificial.

"The cement employed for these tests has given (for one of cement to three of sand for 28 days) a strength in tension of 318 lbs. per square inch, and in compression 3 400 lbs. per square inch. The trass came from Plaidt. The sand was sieved silicious sand. All the mortars had the same consistency. The table below gives the strengths at the end of 28 days.

Mr. Lewis.

	1	2	3	4	5	6	7	8
	1 Cem., 1 Sand.	1 Cem., 1 Trass.	1 Cem., 1 Sand, 1 Trass.	1 Cem., 2 Sand.	1 Cem., 1 Trass, 2 Sand.	1 Cem., 4 Sand.	1 Cem , 4 Sand, 1 Trass.	1½ Cem., 4 Sand.
Strength in tension after 28 days.								
Fresh water.....	425	417	405	334	274	163	225	231
Sea water (N'th Sea)	417	400	394	319	307	150	216	210
Strength in compression after 28 days.								
Fresh water	4 434	4 094	4 094	3 670	3 065	1 953	1 775	2 449

"It is shown from this that rich mortars containing one or two parts of sand do not show any increase of strength in sea water by the addition of trass (columns 1 to 5). Even the mortar of one cement to one trass does not acquire greater strength than a mortar of one cement to one sand. As the single exception, the mortar of one cement, one trass and two sand does show more strength in sea water than in fresh water. It is the opposite phenomenon which is exhibited by all the others. On the other hand, meager mortar, one of cement to four of sand, has been appreciably improved and to the same extent both in fresh water and in sea water, in consequence of the addition of one part of trass (see columns 6 and 7). But we call attention to the fact that the addition of one part of fine sand to mortar one to four increases the strength in tension in the same way about 45 lbs. per square inch both in fresh water and in sea water, a fact which proves that a great part of the influence of trass is due to physical causes (a better filling of the voids).

"The strength in tension of mortar, one cement, one trass and four sand, at the end of 28 days, meanwhile, is not greater in sea water than in fresh water, although Michaëlis found it to be 128 lbs. greater in sea water than in fresh water at the end of 11 days. The disagreement is remarkable in these two contradictory tests.

"We have made some new tests with another brand of cement in mortar, one to four, which have given us the same results with or without the addition of trass. On the other hand, a mortar one to two of this cement has been improved in sea water by the addition of trass. There is reason to notice again in this table that the addition of trass caused a diminution of strength in compression—the addition of one-half a part of cement to a mortar one to four produces at least as much effect as one part trass (see columns 7 and 8)."

Mr. Candlot's argument* against the amelioration of Portland cement by silicious mixtures is as follows:

"The decomposition of mortars by the filtration of sea water or by the frequent renewal of this water in the mass of the mortar has been completely studied and its mechanism is now well understood. The researches of Messrs. Alexander, Debray, Feret and others, have very clearly demonstrated under what conditions mortars are decomposed by the passage of water, and from them we have arrived at this conclusion, that the only remedy to adopt against decomposition is to prevent the sea water from penetrating the mortar. We are led thus to dismiss the chemical reactions of sea water on mortars and to consider their action from a purely physical standpoint. Since all mortars without exception are decomposed when they are transversed by sea water, it is necessary to limit ourselves to ascertaining which are the most compact mortars, and consequently those which oppose to the passage of water the most certain obstacles. Here tests in the laboratory must be

* *Le Ciment*, Paris, September, 1896.

Mr. Lewis. abandoned, for there is nothing to learn from them, and it is necessary to place ourselves under practical conditions in order to be able to take account at the same time of the effects of waves, of difference of temperature, etc. Tests in the laboratory have given us only one point, very important, it is true, but which might have been foreseen; this is the considerable influence of the nature of the sand; we are quite agreed to-day in giving preference to coarse sand, renouncing everywhere the use of fine sand.

"When we study the compactness of mortars, and when we seek to produce mortars as compact as possible, we easily demonstrate that Portland cement possesses in this respect a great superiority over all the other hydraulic products. In our judgment the excellent condition of cement mortars, one to one and one to two, employed at La Rochelle, and in the greater part of the works executed in all the ports of the world in the last fifty years, is due above all else to the fact that Portland cement mortar alone permits us to obtain mortars with a minimum of voids. It is, in fact, the agglomerant possessing the highest specific gravity, and the one which demands the least water for mortar making, while at the same time it is susceptible of fixing the greatest quantity of water.

"Dr. Michaëlis has recently published a study of the highest interest on the decomposition of mortars by sea water. Starting from the idea that the best resisting cements are those in which the lime finds itself engaged in the most stable combinations, he shows that Roman cements contain the least lime susceptible to reacting with sulphate of magnesia in sea water to produce the injurious salts, sulphate and sulpho-aluminate of lime. Portland cement relinquishes during hardening a certain quantity of hydrate of lime which is ready to transform itself into sulphate or sulpho-aluminate of lime Speaking even of the lime of Teil, Dr. Michaëlis says that it ought to resist sea water better than Portland cement. Far from confirming these theoretical considerations, the facts contradict them absolutely, and make it plain that in spite of its chemical composition, perhaps less favorable, Portland cement resists much better in the sea than any other hydraulic product."

The above quotations fairly summarize the views, *pro* and *con*, on this much-discussed subject.

Mr. Belknap. W. E. Belknap, Assoc. M. Am. Soc. C. E.—The writer believes that the importance of the question raised in the paper is hardly appreciated as it should be. It should be sufficient to say in respect to this that the theory and contentions of Dr. Michaëlis, which are exemplified in the paper and have been set forth in the correspondence by Mr. Lewis, are receiving the best thought and attention of cement specialists in France and Germany, and in the latter country the Minister of Public Works has formed a commission to investigate the subject fully. Dr. Michaëlis writes that the experiments under this commission "will be made in the laboratory, as well as in the sea, on large blocks," and will, he hopes, be made to extend over a period of thirty years. Dr. Michaëlis himself has recently begun a new series of experiments to extend over a period of ten years.

While there is much cement work which has stood intact for many years, there have also been grave failures, the causes for which

Mr. Belknap.

are enveloped in much uncertainty. Such work as the author has given is to be much commended and encouraged as being a most valuable contribution to a fund of information, the correct and final analysis of which will sooner or later discover the causes of these failures and enable engineers to determine rules for the composition and treatment of a cement to give certain assurance of its permanent durability under a certain exposure, if a cement can be made to stand it. If it cannot, the information which leads to such a conclusion is just as valuable and important to the engineering profession.

The experiments of Dr. Michaëlis, the author and many others show without doubt that the cements used in them were incapable of resisting the action of various waters and that an admixture of certain materials did improve these cements to such an extent that they withstood the action of the same waters. There are also many practical examples of like incapability in the deterioration of large and costly structures. The writer begs to call attention to an example near at hand, in the very evident deterioration of the quay walls at the Brooklyn Navy Yard. These walls are concrete monoliths formed *in situ*. They rest on a platform, the top of which is at about the plane of low water, and rise about 5 ft. above the plane, being about 10 ft. in height. There are about 3 000 lin. ft. of this wall, which has been exposed from one to three years. The entire surface of it is pitted from 1 to 2 ins. deep and exhibits indications of further deterioration. The writer believes that what are generally regarded as the best brands of foreign and domestic Portland cement have been used in this work. From the uniformly bad appearance of this large stretch of work, one cannot escape the conviction that the cement used was intrinsically incompetent for such exposure, for there is a moral certainty that though the treatment of the cement might have been improper and negligent in some places, it would not have been so throughout the work.

On the contrary, however, and opposed to any general conclusions which might be adduced from these experiments and actual structural failures, are the many works of concrete standing intact for long periods of time. For instance, the German Society of Portland Cement Manufacturers, in its criticism of Dr. Michaëlis' work, cites the sea forts at Copenhagen built nearly forty years ago of cement of the same chemical composition as that "used by Michaëlis in the experiments from which he draws the conclusion that Portland cement is not durable in sea-water."

Also, in like corroboration, is the experience of the New York Dock Department which has built many feet of submerged concrete wall during the last twenty years. This wall, the writer is informed by competent authority, shows no signs of deterioration. It should be noted, however, that the large blocks of concrete which form the sub-

Mr. Belknap. merged portion of this wall are hardened well in the air before being placed and may have sufficient time to acquire a protective carbonate coating which is not decomposed by the salts of sea water.

The following tables are also apparently contradictory to the results shown in Table No. 1. They are selections from some results of tests published in the report for 1895 of M. L. Holman, M. Am. Soc. C. E., Water Commissioner of St. Louis. It will be noticed that whereas the author's neat tests show an increase in strength to the end of the tests, Mr. Holman's show a loss, and whereas the author's sand tests (1 to 4) show a loss of strength after six months in all but one of the foreign brands, Mr. Holman's sand tests (1 to 3) show an increase. It may be stated on authority that in one case the same brand occurs in both sets of tables. In regard to his tests Mr. Holman writes: "The work was carefully done and represents the experience gained from a very large amount of work."

TABLE No. 7.—Showing Results of Tests of Cement, One Part Cement to Three Parts Sand.

Average of 10 briquettes in each case. Sand between No. 20 and No. 30 sieve, one day in air, remaining time in water. Tensile strength, pounds per square inch.

	1	2	3	4
Fineness on No. 100 sieve	86.5	88.6	87.6	91.7
1 week	190 5	223.5	272.0	280.2
2 weeks	207.0	239.8	264.7	284 6
3 weeks	226.1	251.5	265.2	296.9
4 weeks	215.6	287.4	288.5	303.4
3 months	238.6	308.9	317.2	353.7
6 months	252.8	337.4	336.7	421.6
9 months	276.5	332.4	350.1	431.1
1 year	285.6	347.6	386.5	452.5
2 years	306.0	371.1	418.3	480.0
3¾ years	320.3	408.7	442.0	508.0

TABLE No. 8.—Showing Results of Tests of Neat Cement, Mechanically Mixed, One Day in Air, Remaining Time in Water.

Average of 10 briquettes in each case. Tensile strength, pounds per square inch.

	1	2	3	4
Fineness on No. 100 sieve	86.5	88.6	87.6	91.7
1 week	606.2	665.2	559.8	675.6
2 weeks	671.4	693.8	603.4	761.6
3 weeks	664.8	709.4	594.0	768.8
4 weeks	707.0	710.4	625.2	707.2
3 months	756.0	690.6	578.2	675.2
6 months	787.0	657.8	681.2	742.2
9 months	746.4	795.2	828.2	849.8
1 year	742.2	715.0	811.0	783.2
2 years	750.8	764.4	791.8	772.8
3¾ years	655.2	750.2	672.0	689.0

TABLE No. 9.—Showing Results of Tests of Neat Cement, Hand Mixed, One Day in Air, Remaining Time in Water. Mr. Belknap.

Average of 10 briquettes in each case. Tensile strength, pounds per square inch.

	1	2	3	4
Fineness on No. 100 sieve	86.5	88.6	87.6	91.7
1 week	551.2	612 6	524 6	667.0
2 weeks	610.8	645.8	514.8	621.0
3 weeks	633.6	630.0	597.6	721.6
4 weeks	565.8	639.2	581.4	676.2
3 months	665.4	645.0	542.2	659.4
6 months	701.6	661.0	615.6	779.6
9 months	720.8	723.4	645.4	720.0
1 year	710.0	643.8	620.0	716.0
2 years	650.6	654 4	607.4	761.4
$3\frac{3}{4}$ years	709.0	566.4	599.2	614.8

Though the conditions under which the St. Louis tests were made are dissimilar in many respects to those of the author's tests and prohibit any comparison which would seek to make the results of Mr. Holman contradictory to those of the author, they are at variance in a large degree, and emphasize most strongly the previously cited contradictory experience as indisputable evidence of the great uncertainty which attends at present the use of Portland cement for certain purposes.

The writer's experience is in accordance with the theory of Dr. Michaëlis that a large part of the lime is set free during the hardening process and must be finally washed out or taken into combination with external salts. This fact does not seem to be disputed by any of the authorities who have made careful inquiry on the subject. What becomes of it and in what degree its presence in a loose state in the mortar (together with alumina when exposed to sea water) affects the integrity and durability of a cement structure under water is the main point in dispute, in regard to which present testimony is somewhat conflicting.

Whether trass is a necessary admixture to guarantee Portland cement permanently against certain exposures does not yet seem to have been fully determined, though the following statements, which are found in the criticism of Dr. Michaëlis' work made by the German society previously mentioned, seem to favor a conclusion in that direction.

"It cannot be denied that a correct idea lies at the bottom of this theory (of the possibility of improvement).

"Trass acts, particularly in hardening in water, more favorably than other substances because, besides this filling of the interstices, a further condensation of the mortar takes place, through the combination of the trass with the lime separating out from the cement."

Mr. Belknap.

The writer believes the present results of this investigation show that it is much safer to use for sea-water work a cement of low comparative strength in which the basic compounds are comparatively low in proportion to the acid compounds, than to use one of high strength in which the basic compounds are comparatively high. This is simply a preference for future durability over initial strength. He is not, however, of the opinion that such a cement when free from deleterious ingredients will not make durable mortar (in sea water) when mixed in rich proportions, say one to two. The investigation of this subject promises, however, to show how it is possible to make a poorer, therefore cheaper, mortar durable under the same exposure.

In view of the presentation by Mr. Lewis, in his discussion, of the criticism made by the German Society of Portland Cement Manufacturers of Dr. Michaëlis' work on "The Behaviour of Hydraulic Cement in Sea Water," the writer begs to call attention to some extracts from the reply made by Dr. Michaëlis to the same, in which he shows how the association has misinterpreted the results of its own experiments and presents the results of further tests in support of his theory. He says:

"I may remark that the strength of Portland cement *per se*, *i. e.*, of neat Portland cement mortar, is quite of minor importance, and that the strength is not the only important property of cement, that its soundness and durability are even of greater importance. Is it not possible to improve Portland cement without increasing its strength? I affirm that Portland cement can be improved even at the expense of the latter. I proceed now to the examination of the results of the experiment given in Table II (Table No. 10), with which, strange to say, the Board seeks to support its assertion that a practically applicable pozzolana, such as trass, cannot produce an improvement."

The writer inserts here the table as it appears in the criticism of the association with the explanations concerning it.

TABLE No. 10.—Prepared by the German Society of Portland Cement Manufacturers.

	1	2	3	4	5	6	7	8
Kind of Hardening....	1 part cement ..... 1 part sand.	1 part cement 1 part trass	1 part cement 1 part trass 1 part sand	1 part cement ..... 2 parts sand	1 part cement 1 part trass 2 parts sand	1 part cement ..... 4 parts sand	1 part cement 1 part trass 4 parts sand	1.5 pts. cement ..... 4 parts sand
	Tensile Strength at 28 Days.							
In fresh water.....	425	419	405	334	275	164	225	230
In sea water.....	419	400	395	319	308	151	216	210
	Compressive Strength at 28 Days.							
In fresh water.....	4 454	4 111	4 111	3 686	3 079	1 961	1 783	2 469

"The cement used in the experiments yielded the normal tests one cement to three sand, after 28 days a tensile strain of 320 lbs., and a compressive strain of 3 411 lbs. per square inch. The trass employed

came from Plaidt, the sand was quartz sand, retained between the sieves with 380 and 5 800 meshes per square inch respectively.* All mortars were made of the same consistence." Mr. Belknap.

Dr. Michaëlis says:

"In this series of experiments, one of the essential factors for forming a judgment on the matter is unfortunately absent, *i. e.*, the density of the test briquettes; it is only stated that the briquettes are made of the same consistency. But in order to form a mortar out of 1 part cement and 1 part sand of the same consistency as a mortar of 1 part cement and 1 part trass, twice the quantity of water is required with the trass mixture as with the sand mixture; thus, while for the latter one uses about 12 parts of water to 100 dry substance, 24 parts would have to be used with the trass mixture. Furthermore, if we consider that the air-dried genuine trass contains 8% of water, then we have in the sand mixture 12, and in the trass mixture 28 parts water. In consequence of this the sand mixture yields 10 volumes against the trass mixture's 13 volumes.

"If, in spite of this very significant difference in the density of the briquettes, about 2.50 against 2.25,† the trass mortar No. 2 turns out almost as strong as the sand mortar No. 1, then, clearly, a considerable improvement can be recognized as having been effected even in strength; and it cannot be looked upon as strange, or in any way favorable to the opinion of the Board, that the compressive strengths of the trass mixture have turned out lower than those of the so very much denser cement and sand mixtures.

"In all the following mixtures, though less in the same ratio as the proportion of sand increases, the same disadvantage attaches to the trass mixtures; all these contain much more water, and are thus much less compactly made. For example, the mortar No. 3 required 17 parts water (+ 2.7 from the air-dried trass) making nearly 20 parts water, against the mortar No. 4 with only 9.5 parts water. Trass can only harden hydraulically with quicklime; either trass is active as an addition to Portland cement, and then only with the help of the lime separating out from the cement, or it is inactive, and in this case behaves only as so much sand, and even then only as inferior sand from the quantity of clayey matter it contains.

"If we look now at the results of experiments 3, 5 and 7, in comparison with 4, 6 and 8, and if we consider the trass an inactive addition, then No. 3, a mixture of 1 part cement with 2 sand, in spite of its much smaller density, is almost as strong as No. 1 made from 1 part cement and 1 sand; No. 5, a mixture of 1 part cement and 3 sand, almost as strong as No. 4, a mixture of 1 part cement and 2 sand; No. 7, a mixture of 1 part cement and 5 sand, about 50% stronger than No. 6, which is a 1 to 4 mixture; and No. 7 stronger than No. 8, although the latter contains only $\frac{2}{5}$ as much sand as No. 7.

"In each case it is shown how strong the action of trass is already at 28 days.

"And, moreover, it is surely not to the disfavor of the trass mixtures that they produce more mortar.

"That the purely physical increase of strength, which arises from

* "Sand of this grain has been adopted for sea-water experiments by the International Conference because it furnishes a denser mortar, more suitable for marine buildings than coarse sand, and is used likewise in the experiments on Sylt. Michaëlis has used normal sand in his present experiments, with the object of testing porous mortar, which contains a large amount of interstitial space."

† The direct experiment gave the densities to 2.370 and to 1.914—far greater than had been supposed.

Mr. Belknap. the condensing of the cement mortar by addition of fine sand or similar powdered substances to coarse sand (standard sand, for example), can only be very trifling, every expert must know, and that an increase of strength by two- or three-fold can never be produced by this means. Even in spite of this fact, the objection has been raised against my work that I had not brought testimony, that the observed improvement was not entirely attributable to the pulverulent nature of the trass. Although I have again and again demonstrated for 20 years within what limits a physical improvement can occur (I refer also to my report to the London Chamber of Commerce, Cement Section, in 'Engineering,' 5th June, 1896, p. 753), I have begun a new series of experiments, to stretch over ten years, which must convince every doubter. In these experiments were used:—

"(A.) Portland cement, 'Star' brand, of following composition: Silica, 23.027%; alumina, 6.249%; iron oxide, 2.450%; lime, 63.233%; magnesia, 0.916%; potash, 0.660%; soda, 0.069%; sulphate of lime, 2.744%; water and carbonic acid, 0.691%; insoluble, 0.210%; total, 100.249 per cent.

"(B.) The same trass as indicated in my treatise on the 'Behavior of Hydraulic Cements in Sea Water,' and sifted, likewise, through the 76 sieve.

"(C.) Berlin (Freienwalder) standard sand.

"(D.) Fine washed Freienwalder sand, of which

11.4%	passes the sieve with	32 000	meshes	to the	square inch.
16.8 "	" "	16 000	"	"	"
10.4 "	" "	10 000	"	"	"
45.4 "	" "	6 000	"	"	"
16.0 "	" "	2 500	"	"	"

"With these materials the following mortar mixtures were made and gauged into briquettes, which, after 24 hours' hardening in air saturated with moisture, were immersed, part in ordinary water, part in artificial sea water, as specified in my treatise. The sea water treatment was conducted in exactly the same way as was indicated in my first work, only I now allow the briquettes to stand dry for 24 hours each time after the sea water has been run off; by this means they are allowed to drip thoroughly, and the fresh sea water can more easily penetrate them.

"The testing periods from the day of immersion are fixed at 28 and 90 days, 1, 2, 3, 4, 5, 6, 8 and 10 years.

N.	1 part by weight	'Star' cement	9.5 water to
	4 " "	standard sand	100 dry material
O.	1 " "	'Star' cement	10.1 water
	1 " "	trass	to
	6.2 " "	standard sand	100 dry material
P.	1 " "	'Star' cement	9.8 water
	1 " "	trass	to
	8 " "	standard sand	100 dry material
Q.	1 " "	'Star' cement	10.0 water to 100 dry material
	1 " "	trass	
	1 " "	fine sand	
	7 " "	standard sand	
R.	1 " "	'Star' cement	9.3 water
	1 " "	fine sand	to
	7 " "	standard sand	100 dry material

S signifies 'fresh water hardening.'
M " 'sea water hardening.'

"The numbers represent pounds per square inch, tensile strength; the second row in each period, pounds per square inch, compressive strength (obtained from the tensile briquettes bound together again after breaking). Mr. Belknap.

"Up to the present the results of the first three periods, 28, 90 and 180 days, are forthcoming.

Age.	N		O		P		Q		R	
	N S	N M	O S	O M	P S	P M	Q S	Q M	R S	R M
28 days.....	223	182	266	334	184	269	189	270	83	79
90 days.....	306	220	338	427	269	325	277	334	119	111
" "	3 086	2 700	3 714	4 343	2 357	2 557	2 800	3 300	874	963
" density....	2.199	2.242	2.236	2.276	2.177	2.194	2 224	2.244	2 134	2.177
180 days	310	249	394	452	306	378	310	384	126	143
" "	3 314	2 900	3 871	4 430	2 614	3 043	3 085	3 543	957	1 000
" density...	2.191	2.259	2.238	2.287	2.198	2.217	2.240	2.262	2.142	2.187

"These numbers cannot be misunderstood. Above, the supposition was made that trass be chemically inactive, and only act as so much inferior sand in order to lead *ad absurdum* through the results of the experiments of the Board, and asserts that the additions do harm in proportion to their amount. Now trass may be considered as cement, in order to point out the error of those who reckon half the quantity of Portland cement as more effective than trass.

"On the supposition that trass equals cement, the mixtures P and Q are like N, 1 part cement to 4 sand, but P and Q are, even at 28 days, about 50% stronger in tensile strength, and at 90 days Q is also much stronger in compressive strength in the case of the briquettes exposed to the action of the sea water.

"In the case of P, the compressive strength is not superior to that of N only because the P briquettes were made less dense than the N briquettes.

"The tensile tests show, as is seen, the influence of the sea water much more distinctly than the compressive tests, and this is because, with the separation of salt—chiefly calcium-alumino sulphate and not mere magnesium hydrate—causing ultimately the destruction of mortar, there results first a condensing of the mortar which, for a time, increases the compressive strength, till the bursting of the cohesion, the blowing, and therewith the disintegration of the mass take place.

"What the purely physical improvement by addition of fine to coarse sand can amount to, a glance at the mixture R in comparison with P and Q will show.

"I have pointed out that under certain favorable circumstances Portland cement can resist the action of sea water, but that only dense, rich, and therefore expensive, cement mortars can have by chance any permanent durability. I profess to produce, on the other hand, poor and cheap durable mortars out of Portland cement and pozzolana, and I am convinced that this is a matter of great importance, and worthy of all consideration.

Mr. Belknap. "Even if the poor mortars, mixed according to my suggestion, could not withstand the washing out sufficiently long, still much would be gained by the fat impermeable mortar becoming chemically quite durable on the one hand, and much cheaper on the other. The suggestion that through the closing of the pores (colmatage) a protection is formed, as has hitherto been accepted, is a delusion. If this closing of the pores, as is supposed, were caused only by the separated magnesium hydrate, then, doubtless, a favorable effect might be expected from it; but I have found that the separation in the pores, or better, in the mortar mass, under the influence of sea water on hydraulic cement, especially with Portland cement, consists in the main of the destructive agent—calcium sulphate + calcium aluminate – as was but to be expected.

"What surety have we that this separation has only a favorable effect, stopping just as it has increased the density of the mortar, and that it does not proceed farther to destroy the cohesion, break up the mortar, and reduce it to mud? Clearly none; but everything is here left to chance. The proposed mixing of cement and trass, or other valuable pozzolanas, prevents a dangerous reaction with the sea water, and the excessive separation of salts in the substance of the mortar; the stoppage of the pores need not be counted upon with my mortar mixtures."

With respect to the treatise of Dr. Michaëlis, referred to by Mr. Lewis, the following quotations from a letter from Dr. Michaëlis will alter some impressions which might naturally be given by his paper, and also add to the information on this subject:

"At first, I wish to say that I have not at all recommended Roman cements for sea structures; certainly the chemical properties make the best and uniform Roman cements more fitted to withstand the chemical action of sea water; but Roman cements are rarely uniform, and their physical qualities are very inferior to Portland cements. Only the best chemical and physical qualities combined will secure the durability of mortars in sea water. I wish to utilize the high physical qualities and the uniformity of Portland cements, but to improve their chemical deficiency—the over-limed constitution—by adding the very best pozzolanas or hydraulic silicic acid in its densest state. I therefore have recommended for sea structures the mixture of Portland cement with trass (volcanic tufa) or Santorin earth. * * *

"If you will employ one of our best Portland brands * * * combine it with trass or Santorin earth, and take instead of 100 parts by weight of Portland cement, 50 parts cement and 50 parts trass (through the No. 80 wire gauge sieve 900 meshes per square centimeter, equal to 6 000 per square inch), or 60 cement and 40 Santorin earth (same fineness), with such mixtures of hydraulic substances, the sea water can no longer form large quantities of the terrible double salt (the aluminate of lime and sulphate of lime) which crystallizes with 60 or more equivalents of water. The strength and tightness of your mortar compositions are beyond doubt; but take coarse sand, with only 20 to 30% of fine sand in it." * * * "I am not sufficiently acquainted with your genuine American brands; * * * if these are not richer in alumina than the above-mentioned cements, you may use them; but no better Portland cement for sea structures than * * * such brands which contain only 5 to 6% of alumina."

* * * * * * * *

"If you will try trass you must take it in the form of tufa which will bear little duty,* I suppose, and grind it yourself, and the Santorin earth from Fium, in the state of so-called Greek earth. * * * Mr. Belknap.

"1 cu. m. Santorin earth, or about 700 kilos., will cost at Santorin ..... $2 25 to 2 50
1 ton, 1 000 kilos. trass, on the Rhine..... 4 00
1 cu. m. tufa, 650 kilos..... 2 50

With respect to the discussion of Mr. Lesley, the following from another letter of Dr. Michaëlis is pertinent:

"I am not of the opinion of those who accept that by elevating the amount of lime in Portland cement from 1 (silicate) to 2 (lime), in former time to 1 to 2.2 (the average is lower than 2.1), all the failures of modern cement-mortars in sea structures sprang up and may therewith be easily interpreted; certainly the more lime contained in the cement, the more of this body becomes free during the hardening process, and can react with the salts of the sea water, but, first, the strength of the cement increases with the amount of lime, its cohesion or resistance against expansives is stronger; second, with increasing the lime the amount of alumina diminishes, in consequence of that only a smaller amount of the noxious double salt (aluminate and sulphate of lime) can be formed. You see circumstances exist which may compensate themselves. I do not assume that before 1880 the cements have been safer, on the contrary."

The author has given the writer the following analysis of the cements used in his experiments, which information will be valuable in an interpretation of his results:

	a	*b*	*c*	*d*	*e*	*f g h i*
Silica	23.32	20.72	27.18	21.58	25.40	22.5
Alumina and oxide of iron	8.97	11.31	8.11	11.55	6.98	11.7
Lime	63.50	62.73	59.50	60.21	63.91	59.5
Magnesia	0.97	2.13	1.41	1.01	.....	0.9
Sulphuric acid	1.43	0.86	0.99	1.50	1.37	2.85
Residue from silica after treatment with hydrofluoric and sulphuric acids	0.55	0.20	0.74	0.90	0.18	0.40

Moisture, carbonic acid and alkalies not determined.

Andreas Lundteigen, Esq.—It was the author's object to present briefly his own observations, which apparently corroborate the observations of others, to the effect that most Portland cements, however excellent in qualities such as fine grinding, high tensile strength, etc., and however well fitted for use in air and apart from the continuous action of water, are by no means to be relied on in water, especially sea water and water containing sulphates; but that these same cements when mixed with extremely fine silicious materials, such as sil, will, in such waters, give an excellent and fully reliable mortar and consequently concrete, taking it for granted that the aggregate is all right. The author's experiments were not started with the view of publishing Mr. Lundteigen

* The writer was charged no duty on 200 lbs. of trass imported from Andernach.

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them, but simply for his own satisfaction; and this is the reason why the tables of tests were not planned more systematically.

The sand used was clean, natural bank sand, screened as explained, but not washed. The same sand was used for all tests as stated in the paper; it is important to know whether the failure of the sand briquettes was due to the sand or some other cause and to know the remedy; it is the opinion of the author that the sulphates in the water were the cause.

The author said that "it becomes apparent from an inspection of the sand tests in Table No. 1, that those briquettes which broke the highest in a short time fared worst in the long run, and analysis shows that those cements contain more basic elements, lime and magnesia, in proportion to acid elements, silica, alumina and oxide of iron, than the other samples." The first five samples in the sand test in Table No. 1 broke higher at 7 and 28 days than the four last samples, but they were in much the worst condition at the end of two years.

It will be seen from the author's table of analysis quoted by Mr. Belknap that the proportions between the basic and acid elements are as follows:

$$\frac{CaO + MgO}{SiO_2 + Al_2O_3 + Fe_2O_3} = \underset{a}{1.996} - \underset{b}{2.025} - \underset{c}{1.726} - \underset{d}{1.848} - \underset{e}{2.005} - \underset{\underset{\sim}{fghi}}{1.766}$$

The magnesia in sample *e* was not ascertained, but for the sake of comparison is assumed to be 1.0 per cent. Each of the samples *f*, *g*, *h* and *i*, were not analyzed, but were known to be very nearly the same and as previously given. If the sulphuric acid be classed as an acid element then:

$$\frac{CaO + MgO}{SiO_2 + Al_2O_3 + Fe_2O_3 + SO_3} = \underset{a}{1.912} - \underset{b}{1.972} - \underset{c}{1.676} - \underset{d}{1.768} - \underset{e}{1.923} - \underset{\underset{\sim}{fghi}}{1.630}$$

It would at first seem as if there is not enough harmony between these analyses and the tests to warrant the author's statement, but when it is recalled how many things besides the chemical composition influence the quality and the testing of Portland cement, some reason for the assertion may be granted.

The residue from the silica after treatment with hydro-fluoric and sulphuric acid..... $= \underset{a}{0.55} - \underset{b}{0.20} - \underset{c}{0.74} - \underset{d}{0.90} - \underset{e}{0.18} - \underset{\underset{\sim}{fghi}}{0.40}$

From this it may be safely inferred that less of the clay-substance (acid elements) has, in the process of burning, been acted upon by the lime in samples *c* and *d* than in the other samples, and that such good results should not be expected from these two samples as would otherwise be looked for. All nine samples, however, represented good Portland cement, and swelling or cracking would not occur in pure

water. If these samples had been overlimed, in the usual understand- Mr. Lundteigen
ing of the word, or otherwise faulty, then the author would have expected to see the swelling or cracking first in the neat briquettes; as it is, it comes from without, that is, from the contact between the sulphates in the water and the hydrate of lime in the mortar. Thus it can be seen why the sand briquettes, being the most porous, disintegrate first, and why the disintegration first appears at the corners of the briquettes; it also explains why actual masonry, on account of its size, resists the action of such waters longer than do small test bodies; besides masonry as a rule is made as compact and as impenetrable to the water as possible. If the sil or other finely divided silicious material did nothing else but help to fill out interstices and make the mortar or concrete impenetrable by water, it would be of much value; but, besides that, it is, at temperatures above 60° Fahr. at least, able to combine directly with the hydrate of lime and thus become a part of the cementing substance, which fact the following one-

TABLE No. 11.

	Tensile Tests.		Compression Tests.		
	1 cement. 3 sand.	1 cement. 1 sil. 6 sand.	1 cement. 3 sand.	1 cement. 1 sil. 6 sand.	
28 days.....	212	78	1 316	451	The author is aware that the compression tests are proportionately low (the briquettes only 1-in. cube), but they will serve for comparison.
6 months..	321	144	1 927	1 125	
12 " ..	581	218	more than 2 030	1 155	

year tensile test clearly illustrates. Composition, one part slacked, lime, two parts sil, six parts sand; strength after seven days in air and the remaining time in water, 259 lbs.; strength after remaining all the time in a sealed glass jar, 275 lbs.

The water used for all the tests mentioned in the paper was the same, and the author can see nothing contradictory between the tests given in the different tables. The cement used in Tables Nos. 2 and 3 was the same brand as represented by *f*, *g*, *h* and *i* in Table No. 1. The neat, as well as the cement and sand, tests cover only eleven months, so that a decrease in strength could not reasonably be looked for. In Table No. 4 the German cement is the same as *b* in Table No. 1, and the decrease in strength of the sand briquettes between eighty days and twelve months is even more marked than in Table No. 1, because the briquettes were smaller (1-in. cubes) and thus more easily acted on by the water.

The briquettes for each table of tests were made very carefully and

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as far as possible under the same conditions, but the author admits that an average of three breakings is not enough for very accurate results.

The water is neutral to litmus.

At the request of Mr. Maclay the author gives the tests in Table No. 11. Briquettes kept in air all the time.

This table would indicate that no benefit can be obtained by silicious admixtures when the mortar is to remain in air only. Neither would any improvement in this case be called for, as the author has heard of no instance where good Portland cement has failed when exposed to the air only or when guarded from the continuous action of water.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

No. 808.

ADDRESS AT THE ANNUAL CONVENTION AT THE CHATEAU FRONTENAC, QUEBEC, JUNE 30TH, 1897.

By BENJAMIN MORGAN HARROD, President Am. Soc. C. E.

As we meet in this historic city, our Society is, for the second time, the guest of a hospitable neighbor and friend. In 1881 the American Society of Civil Engineers held its annual convention in Montreal. The President was then a man whose memory we recall with professional reverence and personal feelings of the most affectionate character, James B. Francis. In the opening of his address he took occasion to say that the membership was then 636, and that "the most interesting event to the Society, since the last convention, had been the purchase of a house, in the City of New York, as a permanent home, at a cost of $30 000."

It affords me pleasure to be able to state on our return to Canada, after sixteen years, that our membership has increased more than three-fold, being now 2 058, and that we have, during the past year, made arrangement for securing another "permanent home" at six

times the cost of the present one. This we hope, in a reasonable time, again to outgrow. Until then, we will extend a welcome there to our Canadian and other friends of the craft.

For many years the by-laws of the Society made it the duty of the President "to deliver an address at its Annual Convention, giving a summary of the engineering progress during the preceding year." No more appropriate theme could have been assigned for such an occasion, nor could a better method have been advised for preserving a record of such progress, fresh from the hands of those who had largely contributed to it. But the duty was discharged with increasing difficulty from year to year. The field has now become so extended, and the duties of engineers so specialized and exacting, that a satisfactory account of the general progress cannot be rendered by any one participant in the movement.

The rapid growth of societies of engineering specialists has also created opportunities for the performance of this important work with greater fullness and detail. The specification of the constitution is now more considerate, requiring only that "the President shall deliver an address at the Annual Convention," and leaving to him the choice of subject.

I shall endeavor, therefore, on this occasion to present a brief view of the relations of civil engineering to the progress of the present time and country; of its opportunities and limitations, and of the responsibilities and duties of our Society; together with such suggestions as occur to me for promoting its prosperity and influence, as the national exponent of the profession.

The growth of our country in extent, numbers, wealth and comfort is more largely due to the civil engineer than to any other of her citizens. His work has made possible the occupation of the entire continent by cultivated and prosperous communities. Without the post-road, the canal with its incline planes and locks, and then the railroad with its bridges and tunnels, Americans would still be lingering, "a feeble folk," along the Atlantic seaboard, with the Appalachian chain for a barrier, crossed only for curiosity or adventure. To make the recesses of the great Central Valley and the Pacific Slope conveniently and cheaply accessible to all men, to exploit their resources, to turn their waters to the service of life and trade, to connect them with the civilization and markets of the world, and to make them in-

dependent by the diversification of profitable industry, until it now ranges from the extraction of food, material and fuel from the soil and mine to the finished product of the highest skill and organization, was the service of development required in earlier days. Although this work is now, in many of its aspects, approaching completion, and the duties of the engineer in the complex society of the present day are in many respects different from those required when the country was younger, yet they bear a not less intimate and important relation to the public welfare. This has been well expressed by a Past-President when developing, before another audience, the line of thought opened by him at our Annual Convention two years ago.

"The functions of the Government are changing; the demands of the new epoch are not like those of the past; safety from foreign invasion is needed less than safety from dangers which lurk within, from the poisons, both moral and physical, which endanger concentrated population; from bad air, bad water and bad construction; from corrupt administration and from bacteria. In cities and in many communities the duties of the government rest more on good engineering than on legal skill. The whole life of the community depends on appliances and conveniences which the manufacture of power alone has made possible. For all this work the Government needs neither soldiers nor lawyers, but men educated in the various departments which come within the broad definition of the work of the civil engineer. The rulers and governors, who at first were soldiers, who subsequently were selected from men trained as lawyers, must in the future be taken, at least in part, from those who are educated in the utilization of the powers in Nature, from civil engineers, and the men who are equipped with the new education for the benefit of their country."

The new demand for the services of the civil engineer is due to the extension and greater complexity of the social organism, and requires for its supply more varied scientific knowledge. Its field includes the manufacture of power from new sources, air, gas, electricity, and the contrivance of new tools for its utilization. It calls for better sanitation, ventilation, heat and light; the improvement and cheapening of all processes of manufacture; the application of power in smaller units for domestic purposes, and its accumulation in great central plants for commercial distribution; for more rapid transit, both in municipalities and for great distances; for longer bridges, higher buildings and faster steamships; for deeper rivers, harbors and lakes, and for stronger levees.

There is also an increasing demand for the expert administration and development of those departments of great corporations, already established, whether for civic or industrial purposes, which require scientific knowledge, trained judgment, skill in detail, promptness in action, and familiarity with responsibility. These qualities make up the equipment of the civil engineer, and, having been developed by designing and constructing such work, they fit him peculiarly for its maintenance and betterment. Many of the largest and best managed corporations have already placed their administrative and scientific departments in the hands of trained engineers, and are seeking the educated intelligence of graduates of engineering schools for practical positions in their operating departments.

If the function of a learned profession is the increase of scientific knowledge and its application to the promotion of the welfare of society, Civil Engineering has been raised to that position by the learning, character and achievements of its members during the nineteenth century. A knowledge of the forces in Nature by the utilization of which human life has been prolonged, the necessities of life made plentiful and cheap, the comfort and security of all sorts and conditions of men increased, the opportunities of study and travel enlarged, and a new direction given to the thought and energy of the world—this knowledge, on which civil engineering is based, is a part of the liberal culture of the age, and by the possession of it that profession is distinguished from a mechanical art.

If this estimate of what the civil engineer has already done and has still to do for the future development of this country is reasonable, such an occasion as the present is opportune for the consideration of the means by which our duties to ourselves and the public can be best performed, and wherein this can be promoted by an American society, where engineers from all parts of the continent, engaged in any work requiring the scientific application of "the forces in Nature for the use and convenience of man," can meet on common ground and unite, as a body, in such measures as will most efficiently accomplish the objects they have in view.

The attempt has been made by some professions, which has had sincerely in view the public and private interest, to attain these objects, and, at the same time, defend themselves against the Bashi-bazouks of the calling, by protective legislation. I believe that the

experience of the past, in this direction, has not been encouraging, for, on the one hand, the public is disposed to view any such measure with a suspicion and resentment which would be likely to thwart its benevolent intention, and, on the other, the advancement of science is no longer an infant industry, needing protection against the waning powers of ignorance and pretension. It will be more satisfactory, in the long run, if the struggle for existence is allowed to go on, the engineer acquiring his status by hard work, and the people their experience by hard knocks, in order that adjustment may be final and permanent. The tendency is now towards the accomplishment of the same ends by a higher education, more scientific work, and closer personal and professional co-operation among members. In evidence of this is the increasingly thorough and extended courses in the better class of profession schools, the more general employment of trained engineers, and the growth of scientific societies in influence, activity and tone. The School and the Society, rather than the Legislature, are the tools we need for working out our professional salvation.

The same thought may be applied to what are called "codes of professional ethics." Of course, a strong and cultivated moral sense, of which the Golden Rule forms the larger part—absolute good faith and fidelity towards all men, and particularly among fellow-workmen —is the foundation of all social and professional relations, being, perhaps, stronger and more necessary among engineers, in proportion as their responsibilities to the public and to each other are greater than in some other vocations. But this must be a plant of natural growth, with roots deep in the moral nature, made strong and hardy by exposure to the vicissitudes of life, and kept green by professional goodfellowship. A code which has to be proposed, and seconded, and debated, and amended, and passed by a majority vote, can hardly be counted on for the necessary virility in the time of trial. If the principles of such a code met with general acceptance there would be no occasion for its formal adoption. If they were not so accepted, its enforcement would be a matter of doubt and difficulty. If it were not uniformly enforced, a righteous expression and effort would fall into contempt, a desuetude which would not be innocuous, and the last state of that profession would be worse than the first. The prevalence of social order and the progress of humanity and culture is more largely the result of a trained and enlightened public sentiment than

of all the laws and all the courts, and its influence will afford the surest reliance in the conduct of our public and private relations.

I have said that the service rendered by engineers to the community can be made more efficient by their organization in a body for the encouragement of professional fellowship, the comparison of results and the discussion of the problems of the future. Organized co-operation is one of the conditions of progress in engineering, as in other applied, and particularly constructive, sciences.

There is no greater record of constructive skill in the past than the cathedrals and other public buildings of the Middle Ages. This result could only have been accomplished by a wide diffusion of technical knowledge and skill throughout the whole body of craftsmen, by means of their organization into guilds whose object was not, primarily, discipline, but the promotion of social and professional fellowship, and the dissemination of a knowledge of their work. Their contribution to the constructive science and the general culture of their times was very great, and the influence they thus acquired was, for a time, beneficent. They broadly differed, at first, from the organizations of the building trades of to-day in their motives, which were reasonable and humane, and in their methods of work and conduct. But, with increasing power, they became arrogant and turbulent, and sought through protective legislation, special privileges and exclusive rights, which the love of freedom, then growing, would not tolerate. The resentment thus created led to internal strife, general antagonism, and, finally, to their extinction, as uncongenial to the spirit of the times. It is not likely that any similar effort will succeed better in these more liberal days.

In an art, the individual is everything, and the results are not cumulative. The high-water mark of the arts has not been raised for centuries. Its great achievements preserve their relative greatness for ever. Its leaders have not made it easier to write, or paint, or carve, nor, I am sorry to add, have great orators made it easier to deliver an annual address. This is not the condition or limitation of an applied science, which is helpful, and whose results accumulate. Every good piece of original engineering work not only helps the world to live in greater comfort and security, but enables many engineers to do as well, and some to do better. The test of its worth is its absorption into the general body of engineering practice for the use of all men. At first a cap-

stone, it afterwards assumes its orderly and honorable place in the foundations. Those who follow art must all start from the same datum plane, and the point they reach is limited by the span of human life; but engineers may begin where their predecessors left off, and each, in his day, may share the advantage of the dwarf in the proverb, who, mounted on a giant's shoulder, sees farther than the giant.

The reward of the artist is therefore more personal than that of the engineer.

The distinction which I have here tried to indicate is curiously illustrated in the fame left by, probably, the most highly gifted man the world has ever known, Leonardo da Vinci, engineer and artist, pre-eminently, also scholar, soldier, author and philosopher. When the conditions of his time are taken into account, it seems that he excelled his fellow engineers even more than his fellow painters, for Michael Angelo and Raphael were the contemporaries of his maturer life. Yet he is now known to fame almost exclusively as an artist. For one who—wondering at the great locks at the Sault Sainte Marie—remembers him as the inventor of that system of artificial navigation, through which the greatest commerce of the world passes unvexed, there are hundreds who recall with admiration the painter of Mona Lisa and the Last Supper.

Since organized co-operation among the members of a profession affords a stimulus for interest, and an opportunity for the increase and systematization of learning, which is essential for the freest development of the applied sciences, this century, in which the progress of the learning on which these sciences is founded, and the increase of the uses to which they are applied, has been unprecedented in the history of the world, has therefore been specially marked by the birth and growth of scientific societies of all kinds. It was but natural that civil engineers should take a very prominent part in this movement, impelled by the necessity for a more complete organization of their department of knowledge, and the desire for a common ground on which to meet to compare results and collect information for future generalization, and establish kindly personal and professional relations. The lawyer, the doctor and the clergyman—unless he happens to be a missionary—find the scene of their labors where population is concentrated, where their fellows are their neighbors, where libraries are accessible, and an atmos-

phere of culture and learning prevails. On the other hand, a large part—and particularly the earlier part, when the social instinct is strongest—of the lives of many engineers is passed without these advantages and alleviations. Hence, engineering societies, supplying a want otherwise unsatisfied, are numerous and prosperous, and the good civil engineer is apt to be a good society man.

As the growth of physical science, of the knowledge of the forces in Nature, of their laws and methods of application to the demands of the complex civilization of to-day, has been abnormally rapid in this age, that tendency towards specialization, which is more or less observable in all lines of life, has had an unusually marked effect on our profession. To acquire such efficient knowledge of all that is included in the definition of civil engineering to-day as will fit one to deal with each or all of the problems which its practice presents, is beyond the limit of a single life, or the reach of a single mind. We are all necessarily, more or less, specialists, and each one has, and ought, to do what he can do best. The never-ending examination, which we call the struggle for existence, is assigning, or seeks to assign, each of us to the special work for which he is best fitted.

In the primitive days of the world, the wants of a man and his family were so few and simple that he could supply them all himself, courting his wife with a club or lariat, building his shelter, making his clothing, and digging or killing his food. With the increase of personal wants commenced the division of labor. So, in the earlier days of the profession, the demands of the public from engineers were so few and progress was so slow, that a complete knowledge of the arts required to supply them was within the reach of a man of good mechanical ability, combined with the other qualities which make for success in life. But the men of universal knowledge and achievements, like da Vinci, Crichton, or Leibnitz, are figures of the past, and that learning and education which was once called liberal because it was free from limitations, and could range all over the then known world, is now but a tradition. As the knowledge of astronomy has displaced this world, around which the sun, and moon and stellar universe were formerly supposed to revolve for the edification of its inhabitants, from its central position to a subordinate place in a single solar system, so we are all co-ordinated by the growth of scientific knowledge, which

has consigned the best of us to the use of but a few tools, at most, in Nature's workshop.

This is the sufficient reason for the existence and prosperity of numerous societies dedicated to the study and practice of some special department of engineering science. They are so obviously the result of natural and healthy growth, a part of the process of differentiation from the simple to the complex, under the laws of evolutionary progress, that they constitute an important factor in the intellectual and educational influences of the profession.

But there is another plane of cleavage along which American engineers divide. The distances across our country are magnificent, and we, in large proportion, are stationed at the outposts. Frequent resort to a single and far distant center is extremely difficult for men whose employment is so exacting as that of the civil engineer, and, therefore, many are compelled to forego, to a great extent, if not entirely, those opportunities of social intercourse which the Society is designed to promote and which, as experience has showed, contribute largely to the success and interest of professional life. The general recognition of the necessity for social and professional organization for the advancement of the work and interests of civil engineering, combined with an experience of the limitations which are imposed on some of the functions of a national society by the differentiation of the special departments of study and practice, but more especially by the extent of the field over which its members are scattered, has created a natural demand for full and equal participation in all the benefits which organization can confer, and has led to an increase in the number and prosperity of local societies which substantially promotes the growth of scientific knowledge, interest and good fellowship.

This specialization of work and interests which has led to this subdivision of the profession on topical and local lines must, therefore, not only be accepted as part of the natural trend of events, but also acknowledged as an important factor in engineering progress. But it surely involves a tendency towards partial development, and, to that extent, is accompanied by serious peril of atrophy or degeneracy. It might appear, at first sight, that the greatness of both the country and of the profession were obstacles to the adequate development of a national society. On the contrary, the conditions which I have recited are both reasons and incentives for averting this peril by an organiza-

tion whose chief function is the maintenance of the unity and dignity of the profession by the advancement of that general engineering knowledge upon which the successful practice of all its branches is conditioned, and by strengthening the ties of fellowship among American engineers. The accepted philosophy is that one law underlies all truth and its phenomena. One phase of it, the physical forces in Nature, is the foundation of all civil engineering, and a general knowledge of them and their laws is necessary for their successful utilization, in any department, in the service of man. This conviction of the importance of a liberal education as the foundation of eminent success in special branches of learning is now modifying the attitude of other professions and educational institutions. The greater universities of the country are now beginning to require a graduate's degree, as a condition of entrance, from those who propose to follow special courses in law, medicine and theology. The general movement for higher education will, in time, exact equal preparation in civil engineering and the other newer professions. Certainly an organization of educated men, devoted to the advancement and application of a useful science, to secure for themselves a common ground for the exchange of information, the comparison of methods and results, and the collection of material for future work, either by the presentation and discussion of papers, or by personal intercourse, may be considered among the most effective educational agencies of the time. This is more largely true of civil engineering than of other similar societies, on account of their more frequent meetings and the regular and valuable papers and discussions which form so large a part of their proceedings.

Under these conditions, a national society is not only a part, but the head and front of a great system, founded on the necessity for general scientific culture and the fellowship of American civil engineers. It bears the relation to other societies that a university does to a college. It should supplement and round out the work of those societies which specially pursue one branch of learning and practice, by making its prominent function the presentation and illustration of the general truth of engineering science, which is the root and trunk from which all the branches spring.

It represents the Federal idea, and should lead the special and local societies, not only to closer union among themselves, but also with a central institution, with the bond of a common object, of a

love for all knowledge which is included in the constantly broadening definition of civil engineering, and of kindly professional feeling and intercourse. Our ranks are full of the distinguished members of the special and local societies, and, in turn, they have many members who should belong to us, from their eminence and learning, men who do not confine their interest and work to one department of the profession or to the material progress of one part of our common country. It is not too much to say that the prosperity of our Society is closely interwoven with theirs, as the product of the same social and professional instincts.

The subject of a closer alliance between these organizations than at present exists has, on several occasions, received consideration, leading to the conclusion, by both parties, that the conditions favorable for such a measure did not then exist. They probably do not now exist. But it seems to me that the proper mental attitude on this subject is to recognize, as a fact, that some such alliance is natural and desirable; and to seek to promote the conditions which will make it, at some future time, practicable. This view leads to no contention, for persistence in the traditions and policy which have already given to this Society its great measure of success, together with the general pressure for higher education, are the most certain means of bringing about such conditions.

It is true that the idea of professional and social organization can only attain its full development in a national society, and only then, provided its membership is large and represents the highest grade of attainments, its *Transactions* of wide range and high merit, its library comprehensive and accessible, and its home attractive.

The British Institution of Civil Engineers, at its last annual meeting, had under consideration the revision of its terms of admission to membership. Certain changes were then made which, in the opinion of the President, Mr. J. Wolfe Barry, would be found of great value to the outside world, since they would be a guaranty that a member of the Institute, wherever found, possessed that amount of scientific knowledge on which all civil engineering must be based. It would also be of great value to the Institution, raising it, as a body, to its proper position, and enabling it to keep pace with those developments of scientific research which are continually being brought to light.

The requirements for membership of that great society, as they now exist, may be described as opening three ways, through either of

which an applicant may enter: first, professional education, tested by examination, combined with a prescribed amount of practice; second, a prescribed amount of practice, with a professional equipment, tested by the presentation of a satisfactory paper or thesis on an engineering subject; and third, satisfactory proof to the Council of adequate training, practice and fitness, without either examination or thesis.

While this position shows the intention of the British Institution to advance professional and public interests by raising the standard of membership, it may not be assumed, without careful consideration, that a movement along the same line would best accomplish the same object under the conditions of thought and practice in this country. But the expediency of steadily raising the standard of membership is so obvious that it is hardly a subject for discussion. It is rather a part of the general movement of the times for the advancement of learning. On the one hand the preparation for practice is becoming more difficult, from the increase of knowledge, and the duties more exacting from the enlargement of the field of civil engineering work and the variety and magnitude of its problems. On the other hand the professional schools are, year by year, sending out men better equipped and trained for work. So the forces are applied from different directions, and determine the path this Society must follow, if for no higher reason, to keep in touch with the times.

An engineering society, in the selection of its members, cannot follow strictly academic or doctrinaire lines. They may come from the schools, or from other and opposite directions. It must draw its life from every element, and it is entirely likely that the most valuable accessions may be from unexpected sources. Sometimes the engineer, like the poet, *nascitur, non fit*, and, occasionally, a profound insight into Nature's laws comes as did Dogberry's writing and reading. The men who have been drawn into the profession by an irresistible impulse of genius rather than by a carefully regulated training have done their full share in raising civil engineering from a mechanic art to one of the most scientific and useful of professions. It must have a welcome for all who can give satisfactory answer to the questions: What have you done? What can you do? Room must be made for those who have either attained eminence by general practice and learning, or in some special branch of engineering science; for those who conceive and promote great enterprises, and those who elaborate

the methods and details; for those who organize the plant and labor, and assume the responsibility of their prompt and economical performance, and those who enforce their specified execution; for those who administer and develop transportation and manufacturing enterprises already established; for those who improve our rivers, harbors, mines, and alluvial and arid lands; for those who build our land and sea defences; for the scholar in engineering, and for him who has been led, by strong natural faculties, to follow the calling of a civil engineer.

In each of these classes is to be found the required material; and, as the claims of the profession for public confidence are based on practicable achievement, so the best individual claim to any honor or benefit which membership in the Society can confer should rest on the work he who seeks it has done, or can do.

Since the prosperity of the Society is so entirely dependent upon the character of its members, it is important that the machinery of election should be of the most perfect kind. With this object, I believe that certain changes in that part of our constitution regulating elections, which are in the line of the experience of other large associations for social, business, or scientific purposes, should receive consideration. The present system of proposal and investigation, the Membership Committee and the Blue List, is entirely good. But, after them, it remains in the power of those who have not seen fit to express any objections they may have, on the opportunity afforded by the Blue List, or of those whose reasons may not have appeared sufficient to the Board of Direction, to render a verdict of such importance that a prudent man may well hesitate before he accepts the risk, no matter how well he may be qualified. A more serious view is that the present method may occasionally admit of the infliction of wrong or injustice. I believe, for these reasons, that the responsibility of final election could be entrusted to the Board of Direction with benefit to the Society.

The chief function of an engineering society is the preparation, discussion and publication of professional papers. They constitute the reason for its existence, and its claims to consideration. With us, they fill the place of the annual reports of decisions with lawyers, with the advantage that, if we do not like the precedents they establish, we are at liberty to improve them.

The American engineer has not been prolific in the literary work of his profession. We are largely dependent upon foreign countries for

its history and principles. This is but a general statement to which there is an increasing number of exceptions. It is probable that the nature of the engagements of civil engineering in this country has not been as favorable for such work as elsewhere. Here it has been largely in new and remote fields, at stations where privations were encountered, where time was all important, and where the facilities and opportunities for literary work were not available. It is also probable that in the past, at least, a larger proportion of foreign engineers have been equipped with the necessary academic preparation and habit. Therefore the *Transactions* of our Society form the main body of American engineering literature.

The discussions which form a large part of them are extremely valuable. It has been said that pamphlets are apt to be more interesting than books, and foot-notes than the pages to which they refer. There may be many reasons for writing a book, and it may often be perfunctorily done. But it is generally the case that he who writes a pamphlet, or a foot-note, has something which he feels it is important to say, with emphasis. For the same reasons, it is fair to assume that he who enters into a scientific discussion has opinions which are the result of personal study and experience, and which he is prepared to defend with clearness and vigor. They also elicit facts which, while they might not be sufficient basis for a separate thesis, are extremely important, and could be brought out in no other way.

The *Transactions* of the American Society of Civil Engineers are the record of the history of American engineering, and in its list of contributors are the names of those men who have made this history. These volumes are the foundation on which the high character of the Society rests, and by their increase in number and value will the progress of engineering learning and the welfare of the profession be best assured. The importance of this part of the work of the Society imposes a duty on every member, while he is afforded the privilege of access to an audience which he can reach in no other way than by its discharge. The appeal is thus to professional pride and self-interest, and to loyalty to the Society and his fellow members.

The occupation of the New Society House will give opportunity for the development of the library both in extent and usefulness. The proposed arrangements for stacking and reading are excellent. Whether the library is hereafter to be open to the public, to all

seeking information on engineering topics, or is to be a private storehouse for such knowledge, is a subject which seems to me deserving of very serious consideration. The former course appeals to us by its liberality and public spirit, as a measure for the general advancement of learning. I am informed that it will also be accompanied by certain advantage, in a freedom from taxation. It would therefore be in harmony with the policy of the State, for the promotion of knowledge. If, on the other hand, it is decided to make it a close library, the justification for this course would only be found in a great extension of the privileges of its owners, the members of the Society, by facilitating its uses for them in every reasonable way. The first object of a library is not to preserve books, but to get them together in position for convenient use. If this is so thoroughly done that they are rapidly used up, so much the better. Their end has been accomplished, and others can be put in their places. I am aware of the fact that, in the past, the library has been open to those desiring to consult it, and that this was understood to some extent. But in the future the policy of the Society in this matter should, I think, be more clearly defined and widely declared. The happiest solution would combine both access for the engineering public, and extended special privileges to members.

Among the benefits of membership should be the opportunity of conveniently and cheaply securing, by correspondence, an abstract or summary of engineering literature on any point or subject, so far as it may be contained in our library. I believe that this system would meet a reasonable want of many members, for engineers generally have not the constant opportunity of collecting or consulting books that belongs to more sedentary professions. This system would involve an expense for which, at present, the Society may not be prepared, and at the beginning sufficient fees to cover the cost of the service might be required. But as the system and the Society prospered, the application of a part of its revenues to the reduction of these fees would be a proper and legitimate expenditure for the promotion of the main object of the Society, the increase of engineering knowledge among its members.

It would also be a proper subject for consideration, and, perhaps, of experiment, to ascertain if a system of loaning books to members, under certain restrictions, secured by deposit, or otherwise, could not

be devised, with a gain to learning more than commensurate with any loss or trouble that might be incurred. The more modern museums freely lend specimens to responsible naturalists, and, while there is, of course, a certain danger of loss, the advantage to science, through the opportunity of investigation thus afforded, more than counterbalances an occasional mishap. The same practice is increasing in libraries. The public library of New Orleans has now, organized and in popular use, a department, promoted by special gift, known as the "Traveling Library Association." Under this system, any one of several selected collections of fifty standard books is sent to any country town in Louisiana or an adjacent State, on the application of three citizens, for a term of six months, without other expense than the charge for expressage. The only condition attached to this loan is that any loss or damage, other than that from ordinary wear, shall be made good by the payment of the cost or the replacement of the book, and that one of the applicants shall assume the duties and responsibilities of a local librarian. While this system is new in New Orleans, it may be in common use elsewhere. Of course, in a museum, types, certain fossils, and links in a series, are excepted from this liberal custom, just as certain books, such as those out of print, original or special editions, and some others, would reasonably be excepted in a library. I am aware that anything of this kind could only be done under a system that would protect the interest of the many from the carelessness of the few, and the library from serious mutilation. The consideration of the practicability of such extensions of the benefits of the Society is the limit of my suggestions.

And now "dost thou think, because thou art virtuous, there shall be no more cakes and ale?" Shall we not add to the sedate and serious pleasures of "plain living and high thinking," of a sense of useful service faithfully rendered, and of an active and honorable share in the progress and civilization of this wonderful age and country, the social pleasure of that friendly intercourse which lightens work, quickens interest, and sustains enthusiasm. The social faculty is well developed in the *good* civil engineer, and he has not neglected, in this Society, to provide occasions for a most judicious mixture, or blend, of personal friendships with professional benefits.

To such an occasion I have the pleasure and honor of bidding you welcome.

MEMOIRS OF DECEASED MEMBERS.

JAMES LAURIE, Past-President Am. Soc. C. E.*

DIED MARCH 16TH, 1875.

James Laurie, the first President of the American Society of Civil Engineers, was born at Bells Quarry, near Edinburgh, Scotland, on May 9th, 1811. He lived in Scotland for some time, and once, during his boyhood, when hurt through some accident, was found by Sir Walter Scott, who was out fishing. The latter at once abandoned his excursion until he had secured attention for the injured boy.

Among his earliest professional engagements in this country was one as Associate Engineer with James P. Kirkwood, on the Norwich and Worcester Railroad. That line was constructed under their direction in 1835 and subsequently, and was probably the first road in this country on which a tunnel was built. His work for a few years following the completion of the Norwich line has not been ascertained, but in 1848 he was living in Boston, Mass. At that time he had an office at 23 Railroad Exchange as Consulting Engineer for railway location and surveys, dams, bridges and wharves. In July of that year he assisted in founding the Boston Society of Civil Engineers, the oldest existing engineering society in this country.

Very soon after this he became the Engineer of the Central Railroad of New Jersey, and made plans for the extension of the road from Whitehouse to Easton, in 1849. He remained Chief Engineer of this line for about three years.

In 1852 he had an office at 247 Broadway, New York. In the record of attendance at the meeting at which this Society was organized, his name is first. He was one of the leading spirits of the Society during its first two years, and held the office of President for fifteen years.

At the Annual Meeting of the Society, held November 6th, 1867, the following resolution was passed:

"*Resolved*, That we tender our thanks to Mr. James Laurie for his faithful services as our President, for his efforts to re-establish and reorganize this Society on a basis which gives promise of a successful and useful continuance, and particularly for his care of our funds, to which we are greatly indebted for our present unencumbered and hopeful condition."

It is interesting to notice in this connection that the original constitutions of this Society and of the Boston Society of Civil Engineers

* Memoir prepared from papers on file in the Library of the Society, and information furnished by J. W. Adams, W. E. Worthen, Walter Katté, C. H. Myers, Clemens Herschel and G. H. Bishop, Members Am. Soc. C. E., and Mr. Samuel Nott.

are alike in many respects, which apparently indicates that Mr. Laurie's experience at the time of the founding of the Boston association proved useful to this Society during its organization.

In 1855 and 1856 he made a number of examinations of bridges in New York for the State authorities. In 1858 he was employed by the Province of Nova Scotia under a resolution requiring the employment of a competent engineer to report fully on the condition of the Nova Scotia Railway, the sum it should have cost and the expense of various extensions, besides matters relating to the operation of the lines. In 1859 and 1860 he was Engineer of this railway, and prepared plans for various extensions.

In 1862 he made elaborate surveys and a voluminous report on the Troy and Greenfield Railroad and the Hoosac Tunnel, and was retained as Consulting Engineer on this work by the State of Massachusetts for several years.

It was in 1862, also, while Chief Engineer of the New Haven, Hartford and Springfield Railroad, that he designed what is probably his greatest work, the bridge across the Connecticut River at Warehouse Point on the line of the New York, New Haven and Hartford Railroad. The iron work for this structure was bought in England, Mr. Laurie having gone there for the purpose and made a contract with William Fairbairn & Company of Manchester. It is a notable American example of riveted bridge work, one of its spans being 177.25 ft. long. Its many years of service cast no discredit upon its designer, when the increase in weight of rolling stock since 1862 is considered, and especially when it is understood that it is still in service on one of the main trunk lines of the country, while most bridges of the same age of a different form of structure have passed out of existence. The cost of the bridge, erected and completed, was 12.38 cents per pound in gold.

After the completion of this bridge in 1866 it is believed that Mr. Laurie spent his remaining days at Hartford. He was a bachelor and lived at the Allyn House. He was sometimes retained to report on various engineering works, among these engagements being an examination of the Lyman Viaduct on the Air Line Railroad about 1870, and an examination of the Eads Bridge at St. Louis for the bondholders, but as he had accumulated considerable property he lived practically in retirement until his death on March 16th, 1875. He had been ill for some time, and, though not confined to his room, was under the care of a physician.

He was buried in the Cedar Hill Cemetery at Hartford and a granite monument about 25 ft. high was erected on the spot. On one side of this monument there is a bronze likeness of Mr. Laurie, with an inscription below ending: "By his talents and industry he gained the foremost rank in his profession."

His personal clerk and draftsman during the extension of the Central Railroad of New Jersey in 1850–52 was Walter Katté, M. Am. Soc. C. E., who pays the following tribute to his engineering ability:

"I have always felt the deepest respect and gratitude for the great benefit I derived from my experience, short as it was, under him. I learned a great many lessons at that time which have been of incalculable benefit to me since, especially in his exactitude of office methods and the sterling excellence of his designs in engineering practice. Had he lived in this epoch, instead of half a century earlier, he would have assuredly been found in the forefront of our present heaviest and most important engineering enterprises."

MAX JOSEPH BECKER, Past-President Am. Soc. C. E.*

Died August 23d, 1896.

Max Joseph Becker was born at Coblenz, Germany, June 20th, 1828, and was educated in the schools of Coblenz, and at the University of Bonn.

After leaving the University, he passed the requisite examinations for admission to service on the Government Railroad surveys, and in 1848 began his professional career on the Cologne and Minden Railroad in the capacity of "engineer's apprentice" (rodman), with headquarters at Hamm, in Westphalia.

This work was interrupted by the Rebellion of 1848, and by reason of his connection therewith he was compelled to leave Germany, along with such men as Frederick Hecker, Carl Schurz, Franz Sigel, August Willich, and others, whose enforced exile has been our country's gain.

After a brief sojourn in Switzerland, he came to the United States, landing in New York in 1850. His first year's residence in this country was a struggle for a foothold, during which he tried various lines of employment, among others, making surveys in Connecticut for a map-publishing house, as draftsman in an engraving establishment, and even tried his hand at journalism on the staff of the *Abendzeitung*.

In December, 1851, he entered the service of the Steubenville and Indiana Railroad at Steubenville, Ohio, under Jacob Blickensderfer, Jr., M. Am. Soc. C. E., Chief Engineer. His first service with this company was as a draftsman, but this was soon changed to transitman on location, and then to Resident Engineer on construction, in which capacity he continued until the completion of the road in 1854.

* Memoir prepared by William Metcalf, Thomas H. Johnson and Samuel Rea, Members Am. Soc. C. E.

From 1854 to 1856 he held no salaried position, doing such professional work as offered, and occupying a part of his time in making and publishing a map of Coshocton County, Ohio.

In 1856 he entered the service of the State of Ohio as Resident Engineer on the Ohio Canal, and continued in that position until 1859.

From 1859 to 1861 he was Resident Engineer on the Marietta and Cincinnati Railroad in charge of location and construction. During this time he also rebuilt a suspension bridge over the Scioto River, at Portsmouth, Ohio, which had been destroyed by the undermining of one tower during a flood.

During the presidential campaign of 1860 Mr. Becker took a lively interest in the success of the Republican party, and made numerous speeches in German in various towns and cities of Southern Ohio, where the German element was strong. In appreciation of this Abraham Lincoln commissioned him Postmaster at Portsmouth, Ohio. But the drudgery and the red-tape methods of that office were not suited to his taste, and in 1862 he resigned the office and again took service under his former chief, Mr. Jacob Blickensderfer, Jr., at that time Chief Engineer of the Pittsburgh and Steubenville Railroad. Mr. Becker was placed in charge of construction of the Steubenville Bridge and its approaches, one of the most important structures crossing the Ohio River, and subsequently rebuilt by him.

In 1863 he again went to the Marietta and Cincinnati Railroad to take charge of the location and construction of its extension from Loveland, Ohio, to Cincinnati. His connection with this railroad company continued until 1867, when he became Chief Engineer of the Steubenville and Indiana Railroad, which position he continued to fill in the various companies formed by its consolidation with other roads until he at length had charge of the entire system of the Pittsburgh, Cincinnati, Chicago and St. Louis Railway. For nearly thirty years he not only discharged the responsible duties entrusted to him with rare fidelity and ability, but won the confidence and affection of his associates. To the professional acquirements which made his judgment of such pronounced value, he brought a long experience, a well-balanced mind and a fund of sound common sense, which were of the greatest service in the solution of the many important problems that confronted him from time to time in his railway career.

In January last the Board of Directors sought to make his declining years easier, and to that end relieved him of some of his duties, and changed his title to "Consulting Engineer and Real Estate Agent." But the disease which finally carried him off had even then laid its hand upon him, and he was not permitted to enjoy the rest from labor contemplated by this act. After a brave fight, marked by his usual cheerful serenity, he succumbed on August 23d, and the world lost a gallant,

honest gentleman, who had reflected credit upon his profession and who left a name without a shadow of stain or reproach.

The above record is sufficient to show the power and character of the man, who, coming to this country a political refugee, almost unknown and nearly penniless, at once went to work ardently, at whatever his hand could find to do, to make his own living and to be dependent upon no one. In social moments, when led to speak of his early struggles, his account was of great interest; he threw into it a strain of humor which would have made it laughable if it had not been really pathetic. No attempt of ours to repeat his tale could do it justice, because it would be impossible to reproduce his inimitable style; it is sufficient to say that his marked success and steady rise from obscurity to the highest plane of his profession, where he found himself at home, should be an enduring encouragement to all struggling young men who may sometimes, under pressure of a hard fight, get the mistaken notion into their heads that the world is against them.

Mr. Becker's professional and personal standing among engineers was of the highest; he was an honored and beloved member of the Engineers' Society of Western Pennsylvania; he was a member of its Board of Direction for many years, President for several terms, and most useful in every way.

Mr. Becker was elected a Member of the American Society of Civil Engineers on August 7th, 1872, and was made its President in 1889. At the time of his election his personal acquaintance in the Society was not very large, and some questions were asked; before his term had expired he had won all hearts, as he always did wherever he came into touch with people. Mr. Becker was more than an able engineer, he was a man of force, a gentleman, genial and witty, kind and sympathetic, always ready to lend a helping hand. A man without malice or guile, he had no time for animosities, and his memory will ever remain in the minds of all who knew him.

THEODORE G. ELLIS, M. Am. Soc. C. E.*

DIED JANUARY 9TH, 1883.

Theodore G. Ellis received his early technical training in the office of a Boston civil engineer, where he was engaged in minor capacities on a number of railroad surveys. In 1854 he moved to Connecticut to accept an appointment as Assistant Engineer of the Hartford, Provi-

* Memoir prepared from papers on file at the House of the Society.

dence and Fishkill Railroad. He was placed in charge of a surveying party, and afterwards of the construction of the line from Bristol to Plymouth. When this engagement was completed, he visited Mexico to report on mining properties for Boston parties, and one of his papers before the Society contains a description of the Mexican method of making hard lime floors which he observed during his trip.*

On returning to the United States in 1861 he was engaged on a survey of Boston Harbor and afterwards opened an office in Hartford, Conn., as a surveyor. The next year he enlisted in the Fourteenth Connecticut infantry and served in many engagements during the civil war, among them Chancellorsville, Antietam and Cold Harbor. He was frequently promoted, and before the close of the war had been breveted Brigadier-General.

When peace was restored, General Ellis returned to Hartford and resumed his engineering work. He was engaged in 1867 to make a reconnaissance of such portions of the Connecticut River below Hartford as required improvement, and in this manner became connected with the hydraulic works on which his reputation was chiefly founded. He was engaged on the improvements of this river for many years.

One of his best known experimental works was the investigation of the flow of water through large orifices, which he conducted during the summer of 1874 at Holyoke, Mass., with the assistance of Stephen Holman, F. Am. Soc. C. E. This work was described in a paper† read before the Society, which was awarded the Norman Medal, being the second to receive that distinction.

General Ellis was elected a Member of the American Society of Civil Engineers on February 17th, 1869, and a Fellow on November 21st, 1872. He was Vice-President from November, 1873, to November, 1877, and a Director during 1878. He served on many committees of the Society. Among them were two appointed to investigate the failure of dams at Mill River and Worcester respectively, his associates on the committee for the first being James B. Francis and William E. Worthen, and on the second David M. Greene and William W. Wilson. In December, 1875, he was appointed Chairman of a Committee on "American Engineering at the Centennial Exposition," which was subsequently enlarged and changed to the Centennial Commission of the American Society of Civil Engineers. At the eighth convention of the Society, held at Philadelphia during the Centennial Exposition, he delivered the opening address, which was entitled "The Rise and Progress of American Engineering."‡

He was a frequent contributor to the professional discussions of the Society and presented the following papers in addition to those previ-

* See *Transactions*, Vol. ii, p. 179.
† See *Transactions*, Vol. v, p. 19.
‡ See *Proceedings*, Vol. ii, p. 13.

ously mentioned: "The Aneroid Barometer and its Use in Estimating Altitudes," Volume I, page 277; "Experimental Strains upon a Bowstring Trussed Girder," Volume II, page 107; "Causes of Formation of Bars at River Mouths," Volume II, page 23; "The Flow of Water in Open Channels," Volume VI, page 250.

General Ellis died at Hartford, Conn., on January 9th, 1883, in his fifty-third year.

FREDERICK JANVRIN CARREL, M. Am. Soc. C. E.*

Died May 2d, 1894.

Frederick Janvrin Carrel was a native of St. Aubin, Jersey, England, where he was born on October 16th, 1852. After receiving an education at Cardiff and Malvern, he sailed from England for South Australia. Early in 1870 he obtained employment as Draftsman and Assistant in the office of the Engineer-in-Chief of the colony, and was engaged upon plans and parliamentary estimates for the Georgetown and Kapunda, and Narracourt and Lacepede Bay and other railways, and for harbor and bridge works.

In 1876 he resigned and came to this country. His first work was on the surveys for the West Side Irrigation and Navigation Canal, in California, and, after the completion of the field work, was employed in the office on plans and estimates of this canal. Later, he was engaged on the plans and estimates of the Feather River Water Company, which proposed to construct a system of water-works supplying San Francisco. Then he opened an office in San Francisco as Consulting Engineer, and made maps, sewer plans and mine and river surveys for some time.

In March, 1881, he was employed by the United States Government on the Cascades Canal, in Oregon, and was promoted to the position of First Assistant Engineer, remaining in this service until May, 1886. He then moved to Portland, Ore., where he established the Portland Smelting Works, and became interested in the purchase and sale of mining properties and ore. This business occupied most of his attention until his death, which occurred at Spokane, Wash., on May 2d, 1894. In 1890, he was associated with Mr. Oskar Huber in the construction of the water-works at Cheney, Wash.

He was elected a Member of the American Society of Civil Engineers on March 5th, 1884.

* Memoir prepared from papers on file at the House of the Society.

CALEB GOLDSMITH FORSHEY, M. Am. Soc. C. E.*

DIED JULY 25TH, 1881.

Caleb Goldsmith Forshey was born on July 18th, 1812, in Somerset County, Pa. He was educated at Kenyon College, Gambier, O., and at the United States Military Academy at West Point, Grant and Sherman being cadets at the latter school at the same time.

After leaving West Point he resided in Natchez, Miss., where he became City Engineer, and was later, 1836–38, Professor of Mathematics and Civil Engineering at Jefferson College, Washington, Miss. From 1847 to 1853 he resided in the town of Carrollton, now a part of New Orleans, and held the position of Town Surveyor. During 1852 and 1853 he was also connected with the United States Topographical Survey of the Mississippi Delta.

He left New Orleans in 1853 to open a military academy at Rutersville, Tex., which he conducted until 1861. When the civil war began, he entered the Confederate army, although previously opposed to secession, and rose to the rank of Lieutenant-Colonel of Engineers. He was in charge of the defences of Galveston at the time of the capture of that city. After the war was over, he held the position of Chief Engineer of the Galveston, Houston and Henderson Railroad until his return to New Orleans in 1872.

He then began his active work in connection with the improvements of the lower course of the Mississippi River, which occupied most of his attention until his death, and mainly established his reputation as an engineer. Records of his work are given in the "Report upon the Physics and Hydraulics of the Mississippi River" by Humphreys and Abbot, in the proceedings of the Levee Commission of 1874, and the reports of the Louisiana Levee Commission, of which he was a member. He was among the first observers to collect data relating to the physics of the Mississippi River, and was placed in charge of a hydrometrical party in the vicinity of New Orleans by Humphreys and Abbot.

He was one of the founders of the New Orleans Academy of Sciences, its first Vice-President, and chairman of the Sections of Meteorology and Civil Engineering. He presented several elaborate papers on the currents of the Mississippi to that organization and was among the first to draw attention to the possibility of improvements at the mouths of that river. He was an advocate of the St. Philip canal project and opposed the Eads jetty system.

* Memoir prepared from information furnished by B. M. Harrod, G. A. Quinlan and William Starling, Members Am. Soc. C. E.

Possessed of an iron constitution and determined will, he was untiring in his work and indefatigable in his desire to accomplish some good for the welfare of the public, often losing sight of his personal interests in so doing. With a mind prone to and trained in scientific methods, he was charitable in his opinions on everything honestly proposed, but merciless in his open contempt of all that was false or insincere. This last trait of his character militated against a wide personal popularity which his worth fully merited.

He was elected a Member of the American Society of Civil Engineers on August 7th, 1872, and contributed two papers to its *Transactions*, one entitled "The Levees of the Mississippi River," and the other "Cut-Offs on the Mississippi River." He died in New Orleans on July 25th, 1881.

EDMUND FRENCH, M. Am. Soc. C. E.*

Died July 7th, 1860.

Edmund French, the fifteenth Member of the American Society of Civil Engineers, was a native of Connecticut, and, like many of his contemporaries engaged in railway engineering, received a military education.

He was graduated from the United States Military Academy at West Point as the seventh member of the class of 1828, being a classmate of Professor Albert E. Church, the eminent mathematician. He was assigned to the artillery branch, and in 1828–29 was on duty at the Artillery School at Ft. Monroe, Va. He was then assigned to topographical work and remained on this service until 1833, when he returned to Ft. Monroe. In 1833–34 he was stationed in Creek Nation, but returned to Ft. Monroe again in about a year, where he remained, except for a short stay at Ft. King, Fla., until his resignation from the service in May, 1836. At the time of his resignation he was a First Lieutenant of Artillery.

In civil engineering, he had a varied experience. In 1836–38 he was Assistant Engineer of the Croton Aqueduct of New York, and in 1838–47 Superintending Engineer of the Croton Dam and the Upper Section of the Croton Aqueduct. From 1847 to 1852 he was Resident Engineer of the Hudson River Railroad, and its General Superintendent in 1852–57. During 1852 he was also Superintendent of Machinery and Mechanical Engineer of this road. These duties did not occupy all his time, however, for he was General Superintendent of the Troy and Albany Railroad in 1851–57, Chief Engineer of the Newburgh, N. Y.,

* Memoir prepared from information in "The Biographical Register of the Graduates of the United States Military Academy," by General G. W. Cullom.

Water-Works in 1852–57, and Chief Engineer of the Troy Union Railroad in 1852–57.

In 1857–59 he was Assistant Superintendent of the Treasury Building Extension at Washington, D. C.

He died on July 7th, 1860, aged 53 years, at Georgetown, D. C. He became a Member of the American Society of Civil Engineers on November 26th, 1852.

HENRIQUE HARRIS, M. Am. Soc. C. E.*

Died October 10th, 1882.

Henrique Harris was born in 1837, and graduated from the Rensselaer Polytechnic Institute in 1861. He engaged in mercantile pursuits until 1870, when he entered the service of the Department of Public Works of Brooklyn, N. Y., in the capacity of District Engineer. He remained in this position until July, 1873, when he resigned to take charge of the public works in New Brunswick, N. J., under the Commissioners of Street and Sewers of that city. This position he held until the fall of 1878. On March 9th, 1879, he was appointed Chief Engineer of the New York and Manhattan Beach Railway, and held this position for some time. He died October 10th, 1882.

Mr. Harris was elected a member of the American Society of Civil Engineers, December 3d, 1873.

ARTHUR MACY, M. Am. Soc. C. E.†

Died April 14th, 1891.

Arthur Macy was about twenty-five years of age when he became a Junior of the American Society of Civil Engineers in 1877. He was a graduate of the School of Mines of Columbia College, in the class of 1875, and was subsequently an Assistant in the Department of Assaying in that institution for about two years. During the spring and summer of 1876, he varied this work for a short time by acting as Engineer in charge of certain harbor improvements at Sodus Point, N. Y., which were being made by the Ontario Southern Railroad Company. For a short time in 1877 he was Night Superintendent of the works of the Pennsylvania Lead Company at Mansfield Valley, Pa., but was compelled to resign this position on account of poor health.

After a few months spent in rest and mechanical experimenting, he became Superintendent of the Kings Mountain Mining Company of

* Memoir prepared from papers on file at the House of the Society.

† Memoir prepared from papers on file at the House of the Society.

North Carolina. There he remained for about a year and a half, sinking new works, rebuilding mills, and mining and milling ore. Then he went to Colorado and became Superintendent of the Pride of the West Consolidated Mining Company and of the Silver Mountain Mining Company. In the spring and summer of 1882 he designed and built the works of the Martha Rose Smelting and Mining Company, of which he was Manager until ill health compelled him to take another rest.

In the fall of 1883 he became superintendent of the Silver King Mining Company at Silver King, Pinal County, Ariz., where he made many improvements in the mining plant.

Mr. Macy was elected a Junior of the American Society of Civil Engineers on July 12th, 1877, and a Member on December 2d, 1885.

CHARLES LE GRAND McALPINE, M. Am. Soc. C. E.*

Died January 11th, 1884.

Charles Le Grand McAlpine was born in Albany, N. Y., and was educated at the well-known Albany Academy. For many years he was in the Engineer Department of the State of New York and filled various positions of responsibility in the reconstruction and enlargement of the Erie and other canals of that State. He was also in charge of the construction of several railroads, and his last active direction of location and construction was of the Albemarle and Raleigh road in North Carolina, now a part of the Atlantic Coast line.

His father was connected with the construction of some of the first railway and canal works in the United States, and was associated with John B. Jervis, Hon. M. Am. Soc. C. E., in the construction of the Delaware and Hudson Canal and Railroad. The elder brother of Charles was William Jarvis McAlpine, the third President of the Society, and afterwards an Honorary Member. His extended professional works and his aggressive individuality have made his name notable among American civil engineers. Charles was of a more retiring disposition, with much reserve and dignity of character. With a large experience and a trained judgment in engineering problems, he never sought notoriety. He was, however, a capable adviser in works of importance, and his aid and counsel as consulting engineer were constantly sought by managers and investors in large undertakings.

For a number of years he lived in the city of New York, acting as consulting engineer. He died in that city, January 11th, 1884. His widow was the daughter of the late Thomas Farrington of Tioga County, N. Y. Mr. McAlpine became a member of the Society December 4th, 1867.

* Memoir prepared by John Bogart, M. Am. Soc. C. E.

ROBERT NEILSON, M. Am. Soc. C. E.*

DIED OCTOBER 12TH, 1896.

On the northern shore of Lake Ontario, about 25 miles west of Kingston, is the hamlet of Sandhurst, known also as Fredericksburg, situated in Lennox County, Province of Ontario, Canada. In this place Robert Neilson was born, August 19th, 1837. His parents were Thomas and Eliza Neilson, his father's occupation being that of a farmer.

His boyhood was spent on the farm, and when he became old enough he took active part in the details and management of the work. His early education was received in the schools of his native place, and the improvement of his opportunities fitted him at the age of 19 to become a teacher. He taught in the schools of Fredericksburg from 1856 to 1858, and at the same time prepared himself for entrance to the Polytechnic Institute, at Troy, N. Y., where he began his course in the fall of 1858. He was graduated from this institution in the summer of 1861, and returned to his home intending to follow his chosen profession of civil engineering in his native country.

He made efforts to obtain employment under the Canadian government, but finding that considerable time was necessary to effect this purpose, he again found occupation in farming and as a teacher in the schools of Napanee, near his father's home. This occupied the year 1862 and part of 1863.

In October, 1863, he came to the United States and entered the service of the Pennsylvania Railroad Company as rodman on the construction of the Philadelphia and Erie Railroad, which was opened about a year later. In March, 1864, he was appointed Assistant to Mr. A. J. Cassatt, then Resident Engineer of the Middle Division of the Philadelphia and Erie Railroad between Renovo and Kane, Pa. In September, 1865, he was chosen to succeed Mr. Cassatt as Resident Engineer, and it was during his residence at Renovo that he married Elizabeth J. Wright, June 25th, 1866. His ability as an engineer was again recognized by his appointment, January 1st, 1868, to the position of Resident Engineer of the Middle Division of the main line of the Pennsylvania Railroad between Harrisburg and Altoona.

On the morning of July 17th, 1868, five spans aggregating 830 ft. of the west end of the Pennsylvania Railroad Bridge over the Susquehanna River at Rockville, about 5 miles from Harrisburg, were destroyed by fire. This was a wooden deck bridge of the usual Howe truss form. Mr. Neilson soon reached the scene of the catastrophe, and as trestling

* Memoir prepared by E. D. Nelson, Esq.

could not be well adopted, it was decided to rebuild the permanent bridge at once. It was necessary to remove the wrecked spans, to have the timber sawed and to order the rods, angle blocks and other parts and assemble them at the bridge. The material began to arrive on the third day and the work moved rapidly to completion, the bridge being opened to the passage of trains on July 28th, hardly twelve days after its partial destruction.

Many similar instances might be cited to show his quick comprehension in emergencies, his ready judgment as to the best course to pursue, and his promptness in completing the work in hand.

In January, 1870, he was promoted to the superintendency of the West Penn Division of the Pennsylvania Railroad, which position he held until his transfer, in September, 1874, to the Elmira and Canandaigua Divisions of the Northern Central Railway, as Superintendent. During his superintendency of these divisions he was obliged to take an active part in traffic matters in addition to the duties relating to engineering and transportation which usually devolve upon a railroad superintendent.

His success in all of these departments of railroad work most justly earned for him his promotion, in September, 1881, to the position of General Superintendent of the Philadelphia and Erie Railroad and the Northern Central Railway, north of Harrisburg. In January, 1883, his jurisdiction was extended over the entire line of the Northern Central from Baltimore north, and he continued in this position, as a notably successful operating officer, till the time of his death, October 12th, 1896, at his home at Williamsport, Pa.

His personal characteristics greatly endeared him to his subordinates and associates. Firm in purpose, yet always kind and considerate, he directed his subordinate officers more by his own strong personality and the evident wisdom which he possessed, than by the harsher methods of arbitrary authority; and he built up those under him with the knowledge which by his long experience and clear mind he had gained.

He never refused counsel or advice to those who asked, and he showed a personal interest in the affairs of those who sought his help, which added to the esteem in which he was held by all who came in contact with him.

In the death of Mr. Neilson the Pennsylvania Railroad Company lost one of its most efficient operating officers, and the profession an engineer of pronounced ability in railroad construction and maintenance.

Mr. Neilson was elected a Member of the American Society of Civil Engineers on February 17th, 1869.

JAMES HART RENO, M. Am. Soc. C. E.*

Died August 5th, 1881.

James Hart Reno began his professional career in 1866, when he was about nineteen years old, as Assistant Engineer in charge of the construction of about 8 miles of road on the Allegheny Valley Railway. Early in 1868 he left this position to become a transitman in a party on the Union Pacific Railway in Utah and Nevada. Early in the fall he was given a subdivision on construction in Nevada, which was abandoned later in the year and all the force brought to Utah. There he had charge of construction on the western side of the Promontory, and remained in the service of the company until late in June, 1869. For a few months in the latter part of that year he was Assistant Engineer on the location and construction of the Adirondack Company's roads, and he then entered the service of the Northern Pacific Railway Company. He remained about two years with this company, and had charge of the location and construction of about 93 miles of road. In May, 1872, he took charge of the survey and preliminary location of the line of the Texas and Pacific Railway from San Diego, Cal., to Pinos Villages, Ariz., a distance of 375 miles.

In May, 1873, Mr. Reno began another branch of engineering, as Assistant Engineer in charge of the street construction of the city of Pittsburg, Pa., which work was continued until January, 1877, when he was appointed County Engineer and Surveyor of Allegheny County, Pennsylvania, in charge of all the public structures of the county, including bridges and buildings.

He was elected a Member of the American Society of Civil Engineers, November 5th, 1879.

JOSEPH RUSSELL THOMAS, M. Am. Soc. C. E.†

Died November 28th, 1896.

Joseph Russell Thomas was first actively engaged in engineering works during the period when the construction of American gas works was passing from the control of British contractors to those of this country. He was born in Burlington, N. J., on March 11th, 1820, and was educated in the Philadelphia public schools. He learned the trade of a carpenter, but abandoned it to engage in the grocery business.

* Memoir prepared from papers on file at the House of the Society.

* Memoir prepared from papers on file at the House of the Society.

About this time the Camden Iron Works, at Camden, N. J., were started by Messrs. J. W. & J. F. Starr, who placed the gas division of their establishment under the charge of Samuel A. Thomas, an elder brother of the subject of this memoir. It was through the influence of this brother that Joseph A. Thomas was engaged on a Starr contract for vessels under construction at Hoboken. When the work was finished, he entered the employ of Messrs. Stevens of that place, and was engaged on the construction of the "Stevens battery."

By this time, however, the gas business of the Camden works had increased to an unexpected extent, and Mr. Thomas believed that it was destined to still greater development. In 1848 he moved to Camden and entered the employ of the firm. His spare moments were spent in studying engineering subjects, and his aptitude for applying theory to practice soon led to his appointment as superintendent of construction of the firm's contract.

His first undertaking was the erection of the plant of the New York Gas Light Company on the East River between Twenty-first and Twenty-second Streets to replace an old plant which was located at Center and Hester Streets. The work was carried on in 1850–51, being interrupted during the winter by the erection of a gas plant at New Brunswick, N. J., of which Mr. Thomas was likewise superintendent of construction. When these works were finished, he built the plant at Norfolk, Va., for the same contractors.

Somewhat later Mr. Lemuel Davis, of Detroit, Mich., engaged him to rebuild the gas works in that city. These works had been in operation a short time, but had already proved inadequate to the demands of the city, which was growing rapidly. When the work of remodeling the plant was completed in 1852, Mr. Davis is reported to have been so satisfied with the manner in which the undertaking was carried through that he added a substantial bonus to the amount due Mr. Thomas. By this time the latter had achieved a good position among gas engineers, and his services were in considerable demand. He finally became associated again with Mr. J. W. Starr, this time in connection with the Williamsburgh Gas Light Company.

In 1854, when Mr. Thomas was elected engineer and superintendent of this company, Williamsburgh was a straggling suburb of Brooklyn, N. Y., occupying such land as rose above the marshes north of the latter city. It was not a pleasant place and seemed destined to grow slowly. The local gas works was apparently in keeping with the territory it supplied. It is reported to have been an ill-located, ramshackle affair, steadily drifting toward insolvency. The new superintendent had received at Detroit a good preliminary training for the management of such a plant, however, and he soon had affairs on a satisfactory business basis. Williamsburgh and Brooklyn were united politically, and the marshes between the two districts were filled

in. The demand for gas increased rapidly, and under the direction of Mr. Thomas, who was elected a director of the company in 1855, the plant was reconstructed and enlarged until it became one of the best known for completeness of equipment in the country.

In 1883 he severed his active connection with the company's affairs, and became the editor of the *American Gas Light Journal*, a position he held until his death. He also continued his extensive practice as consulting engineer, among his most notable engagements being the design and construction or reconstruction of the plants at Flushing, College Point, Jamaica, Fishkill, Tarrytown, Sing Sing and Poughkeepsie, N. Y., and Long Branch, N. J. The works at the last place he not only built, but also operated for a time until it was in good condition financially.

Although afflicted with serious deafness in his later years, he never lost his interest in the public affairs of Williamsburgh, and was a trustee for many years of the Williamsburgh Public Dispensary, and the Williamsburgh Public Library Association, and was one of the most liberal patrons of the Brooklyn Art Association. He was elected a Member of the American Society of Civil Engineers on October 5th, 1881, and was, in addition, a member or honorary member of the New England Association of Gas Engineers, the Western Gas Association, the Ohio Gas Association, the Guild of Gas Managers and the American Gas Light Association.

Mr. Thomas died at his country home at Glen Ridge, N. J., on November 28th, 1896, after a long illness. His wife and a daughter survived him.

MARSHALL MARTAIN TIDD, M. Am. Soc. C. E.*

Died August 20th, 1895.

Marshall Martain Tidd was born in Woburn, Mass., August 1st, 1827. His early education was obtained in the public schools of Woburn. He lost the use of his right arm when a young child, owing to a fall upon the back of his head which resulted in the paralysis of the arm. Notwithstanding this, he was a very active and capable boy, and delighted in all kinds of out-of-door sports, such as swimming, sailing, canoeing, hunting, fishing, skating, etc., in all of which he excelled, notwithstanding the loss of his arm. He was expert in the use of tools and made many ingenious articles that required skilful work.

At the age of sixteen he went to work on the old Middlesex Canal, and for about two years attended one of the locks in Woburn.

* Memoir prepared by Henry Manley, Dexter Brackett and F. C. Coffin, Members Am. Soc. C. E.

He began his engineering experience as an assistant on the construction of the dam across the Merrimack River at Lawrence, Mass., under Charles S. Storrow, Hon. M. Am. Soc. C. E. This was before the days of photography, and one of Mr. Tidd's duties was to make freehand sketches showing the condition of the work at the end of each month. After the completion of the Lawrence dam he was occupied in drawing on wood and stone for illustrations of machines and mechanical devices. This business he followed for about 25 years, until the introduction of cheaper processes, and the increase in his more strictly civil engineering work caused him to abandon it. He displayed much ability in the use of pen, pencil and brush, his drawings being remarkable for their extreme accuracy and fineness of detail.

During these years he was connected with the construction of the Simpson patent wooden dry docks in East Boston, Mass., and Portland, Me., and was Consulting Engineer and Designer of the dry dock at the Erie Basin in Brooklyn, N. Y.

In 1872 Mr. Tidd was elected Water Commissioner of his native town, the only public office he ever held. Although holding the office of Water Commissioner, he was also practically Engineer of the works, and his connection with these works led to his being engaged to design and superintend the construction of works of a similar character in other places, so that from this time to his death he devoted himself almost exclusively to questions relating to water supply and sewerage.

He designed and superintended the construction of works for the water supply of Natick, Lincoln, Hingham, Marlboro, Hudson, Weymouth, Hyde Park, Cohasset, Randolph, Holbrook, Vineyard Haven, Reading, and Fairhaven, Mass.; Lewiston, Gardiner, Richmond, Calais, Caribou, Dover, Foxcroft, Farmington and Madison, Me.; Hanover, N. H.; St. Stephen, N. B.; Charlottetown, Prince Edward Island; Yarmouth, N. S., and Ashland, Ky. In addition to the preceding he was employed to make improvements or additions to existing works in Fort Smith, Ark.; Tiffin, O.; Woonsocket, R. I.; Manchester and Nashua, N. H.; Bath, Brunswick, Waterville, Bangor, Bar Harbor, Me.; Medford, Melrose, Belmont, Maynard and Attleboro, Mass.

He was employed as an expert to report to capitalists upon the condition and value of many works in the West, also as an expert in cases of the taking of the works of private corporations by municipalities, at Syracuse, N. Y.; Auburn, Me.; Rochester, N. H.; Braintree, Haverhill and Quincy, Mass., and Milford, N. H.; as Consulting Engineer at Helena, Mont., and Phœnix, Ariz.; by the Maine Water Company, Cambridge, Mass., and others. He also designed and built the sewerage system at Marlboro, Mass. At the time of his death, he was employed upon the Bath Water-Works, Me.; the construction of the Woburn sewerage

system, the plan of a sewerage system for Stoneham, Mass.; Bar Harbor, Me., Water-Works, and as Consulting Engineer on the Willimantic, Conn., Water-Works, and Cambridge, Mass., Water-Works; he was also retained as one of the board of arbitration in a suit for mill damages against the town of Attleboro, Mass.

As an engineer, Mr. Tidd's most striking traits were remarkable mechanical ability, keen observation, fertility of resource and entire and complete honesty of purpose.

He was very successful as an expert witness in legal controversies, he had a strong memory, was very careful in the collection of his data, and had a blunt, emphatic manner of stating his opinions which made him an excellent and convincing witness. As an expert engineer he had a very wide practice in the examination of proposed and existing works, and his familiarity with certain branches of mechanical engineering, acquired in the early days when a civil engineer was necessarily a mechanical engineer as well, resulted in his being retained frequently by mill owners.

To know a man completely it is necessary to know his recreations as well as his work. In earlier life Mr. Tidd's recreations were of the active out-of-door sort; later in life, perhaps his greatest interest was in horticulture and the care of his grounds. For a man of moderate means, he had a very fine collection of shrubs, his flowers, fruit trees and lawn were kept in the best of order and his grounds showed remarkable taste. He was a life member of the Massachusetts Horticultural Society, and was wonderfully well informed in all the details of raising fruit and flowers and the care of shrubbery. Another of his interests was his workshop, which was a model in its equipment of tools and their neat arrangement.

His other principal recreation was attendance upon the meetings and excursions of the several engineering societies of which he was an enthusiastic and liberal member.

In his relations with the members of his profession, he was liberal and generous, ever ready to impart freely to a brother engineer who came openly to him, from his knowledge, or the result of his experience.

He was married when about twenty-eight years of age to Abba S. Cole, who died in July, 1893. He had one daughter who survives him, as does also his aged mother.

He was a man of pronounced individuality, active and alert, both of mind and body, an excellent companion, clear-minded, frank, open and generous.

He became a Member of the American Society of Civil Engineers, October 2d, 1878. His death was occasioned by heart failure, the result of a severe attack of the grippe, about two years before.

ALEXANDER SAMUEL DIVEN, F. Am. Soc. C. E.*

DIED JUNE 11TH, 1896.

Descended from Scotch-Irish ancestry, General Alexander Samuel Diven was born February 10th, 1809, in the then town of Catherine, Tioga County, N. Y., now the town of Dix, Schuyler County. He was the son of Captain John Diven, a soldier of the Revolution.

General Diven's early education was acquired in the schools of his native town and in the academies at Penn Yan and Ovid. In 1830 he went to Elmira and entered the office of the late Judge Hiram Gray as a student at law. In this office and that of Fletcher Haight at Rochester he completed his legal studies, maintaining himself in the mean time in part by teaching school in Elmira, and in part at Owego as Deputy County Clerk of Tioga County, which then comprised Chemung County and the present city of Elmira. Admitted to the bar he went to Angelica, Allegany County, in 1833, and opened an office in partnership with George Miles, who a few years later removed to Michigan. General Diven continued his practice alone at Angelica until 1845, when he removed to Elmira. His practice in Angelica was extensive and covered a large portion of western New York. Soon after removing to Elmira he became a member of the firm of Diven, Hathaway and Woods, which, during its existence of fifteen years, was a leading law firm in southern New York. This partnership continued until July, 1861, when it was dissolved to enable its senior member to form a new partnership with his son, George M. Diven. This latter partnership continued only a few years and did not receive much attention from its senior member, owing to the demands upon him of his political, military and business associations. A free soil democrat, General Diven was one of the organizers of the Republican party in the State of New York, and was ever prominent in its councils. He served one term, 1858–59, in the State Senate, and in 1860 was elected a representative to the Thirty-seventh Congress, taking a leading part in its deliberations during that critical period in the nation's history.

In the summer of 1862, after the disastrous Peninsular campaign, when the call was issued for 300 000 men, at the personal solicitation of President Lincoln and Secretary Seward, General Diven and General R. B. Van Valkenburgh, representative from an adjoining district, leaving their seats in Congress, went to their homes to aid in raising a regiment in response to the call. This regiment, the 107th New York, was one of the first, if not the first, to respond to the call. It went out with General Van Valkenburgh as its Colonel and General Diven as

* Memoir prepared by G. M. Diven, Esq.

Lieutenant-Colonel, and reached the front in time to take part in the battle of Antietam. Failing health compelled General Van Valkenburgh to resign his command, and General Diven succeeded to the colonelcy, continuing in command until after the battle of Chancellorsville, in which the regiment took part. Soon after this battle he was commissioned by President Lincoln as Brigadier General, by brevet, and appointed Assistant Provost Marshal General and assigned to the western district of New York, with headquarters at Elmira. This position he continued to hold until the close of the war.

While residing at Angelica, General Diven became interested in the construction of the New York and Erie Railroad and took an active part in extricating the company from its early difficulties and especially in aiding it to procure needed legislation, particularly that which released the company from the loan of $3 000 000 by the State. For several years he was Director, had charge as Commissioner for procuring right of way over a large portion of the line, and with his firm had charge of the legal business of the western end of the line. His connection with this road and its construction brought him into close relations with men eminent in their profession, who, as civil engineers, had charge of the work, among them Major T. S. Brown, William J. McAlpine, James P. Kirkwood and Julius W. Adams.

While engaged in the construction of the New York and Erie Railroad he became interested in the Chemung Railroad, extending from the New York and Erie Railroad, near Elmira, to the then village of Jefferson, now Watkins, at the head of Seneca Lake. He was a director in the company which built this road, which was opened in December, 1849, soon after the Erie Road was opened to Elmira and was operated in connection with the latter road as a continuous line from New York to Jefferson for a couple of years and until the completion of the line to Dunkirk. Soon after the completion of the Chemung Railroad General Diven became interested in the construction of a line from its northern terminus to Canandaigua. The company which constructed the latter road was originally chartered as the Canandaigua and Corning Railroad Company for the purpose of constructing a railroad from Canandaigua to Corning. After the construction of the Chemung Railroad the title of the Canandaigua and Corning Company was by legislative enactment changed to the Canandaigua and Elmira Railroad Company and its route changed to connect with the Chemung Railroad, thus making a continuous line of railroad from Elmira to Canandaigua. The contract for its construction was made with a company of which General Diven was a member. After the completion of this road a still further extension was made by the construction of the Canandaigua and Niagara Falls Railroad, which was also constructed by the same firm of contractors. These three railroads were constructed with a 6-ft. gauge to correspond with that of the New York and Erie Railroad,

and formed a continuous broad-gauge line from Elmira to Niagara Falls. The last built road becoming involved, it was sold on foreclosure, purchased in the interests of the New York Central Railroad Company, its gauge narrowed, and has since been operated by that company. The line from Elmira to Canandaigua is now under the control of the Northern Central Railway Company and is operated by it as a part of the Pennsylvania system in connection with the Elmira and Williamsport Railroad. Soon after the completion of the road to Canandaigua General Diven became interested in the construction of the Williamsport and Elmira Railroad. The Williamsport and Elmira Railroad Company was originally chartered by the legislature of the State of Pennsylvania in 1832, this being one of the earliest railroad charters in the United States. At an early day a line was constructed from Williamsport to Ralston and for a time operated with horses, but was soon abandoned and not used until about 1852, when General Diven took hold of the project, interested certain Philadelphia parties to raise the necessary capital, and, taking the contract for its construction, completed the road in the summer of 1854. While this road was under construction he was also interested in the construction of the Catawissa Railroad, extending from Milton to Tamaqua in the State of Pennsylvania, which, when finished, in connection with the Williamsport and Elmira and other roads formed a continuous line of railroad from Elmira to Philadelphia.

Shortly after the completion of these railroads he became interested in the construction of the main line of the Missouri Pacific Railroad, and was one of the firm of James P. Kirkwood & Company, which had a contract for constructing a large portion of the line. Afterwards, in connection with Lewis J. Stancliff, who had been a civil engineer in the construction of the Erie Railroad, and others, he formed a firm of contractors known as Diven, Stancliff & Co., which took the contract for constructing what was then known as the Southwest Branch of the Missouri Pacific Railroad, a line projected from Franklin on the main line of the Missouri Pacific to Neosho, in the southwestern portion of the state. This line was completed to Rolla, and the firm was engaged on heavy work beyond, when the breaking out of the Rebellion stopped operations.

Upon the reorganization, after the foreclosure sale, of the New York and Erie Railroad Company into the Erie Railway Company in 1862 under the presidency of Nathaniel Marsh, General Diven was elected a Director, and his law firm, then consisting of himself and son, had charge of the legal business of the company west of Susquehanna. Upon the death of Mr. Marsh, soon after the close of the Civil War, General Diven was elected Vice-President of the company, a position he continued to hold, residing meantime in New York City until 1871, when he resumed his residence in Elmira. He again took the vice-

presidency for a few months in 1872, when General Dix was called to the presidency. During this period, in connection with one of his sons, he was interested in a contract for the construction of the Jefferson Railroad, extending from near Susquehanna to Carbondale, Pa., which is operated as a branch of the Erie Railroad. With another son he afterwards constructed what is known as the Nineveh branch of the Albany and Susquehanna Railroad, extending from Nineveh to a connection with the Jefferson Railroad, constructed under the auspices of and operated by the Delaware and Hudson Canal Company. Still later he was engaged with the same son in the construction of a portion of the New York and Canada Railroad along the west shore of Lake Champlain.

With the completion of this work he closed active operations in business affairs. The rest of his life was spent at his old home in Elmira, except for the last twenty years he passed a few months each year at his winter place on the St. John's River, near the city of Jacksonville, Fla. While engaged in no regular active business, he kept himself in touch with the progress of events, took great interest in political affairs, and devoted much of his time and means to benevolent and educational institutions and enterprises. During nearly all his life he was an earnest and active member of the Presbyterian Church.

General Diven was married in 1834 to Amanda M. Beers, who died in 1875. Eight children, four sons and four daughters, were the issue of this marriage, of whom two sons and three daughters survive him. One of the surviving sons, John M. Diven, superintendent of the Elmira Water-Works Company, is an Associate of this Society. A second marriage took place in 1876 to Maria Joy, who still survives.

While the compiler of this sketch feels some delicacy about commenting on the character of the deceased, he may be pardoned for closing with the tribute of another, showing the esteem in which General Diven was held by those who knew him best. For many years he was a member of a select social and literary club which held monthly meetings, and at the first meeting of the club after his death a member prefaced the essay he was to read with the following words:

"I should do less than justice to the emotion of the hour did I fail to voice our sense of loneliness at loss of him but yesterday the Nestor of our circle, so ripe in years, so strong in heart and mind, who since our last meeting has solved the magnificent mystery of death. To his ready soul doors have now swung open, upon whose threshold we have knocked in vain these many years. We shall not forget him. The sparkle of his wit, the dignity of his thought, his kindly sentiment to us each and all, as well, shall linger in our memory till the last of this little circle shall have ceased from earthly effort and followed in his departing footsteps."

General Diven was elected a Fellow of the American Society of Civil Engineers on June 16th, 1870.

JAMES FREDERIC JOY, F. Am. Soc. C. E.*

DIED SEPTEMBER 24TH, 1896.

James Frederic Joy was chiefly noted as the man who once probably, saved the State of Michigan from bankruptcy, although he was also prominent through his connection in important capacities with many of the great railway companies which developed the Central States with marvelous rapidity in the ten years immediately preceding the Civil War. Like many of the men who were conspicuous figures in the railway work of that period, Mr. Joy was a farmer's son. He was born December 20th, 1810, at Durham, N. H., and was brought up in the frugal, industrious manner characteristic of New England country life at the time.

He attended such schools as he could, and finally became himself a teacher in one of them. With the money earned in this way and a little assistance from his father, who was in not very good circumstances, he entered Dartmouth College. He graduated in 1833 and was selected to deliver the valedictory address. Modern languages, particularly French, and history were his favorite studies, and he retained his interest in them to the close of his life, one of his hobbies in later years being the collection of books relating to Washington and the Revolutionary War. From Dartmouth he went to Cambridge and entered the Harvard Law School, where Joseph Story took a particular interest in him. He had to leave Cambridge, however, in a short time and go back to teaching to earn enough money to carry him through the school. He became a preceptor in an academy at Pittsfield and also an instructor in Latin and Greek at Dartmouth College, and after a short time succeeded in laying by enough of his earnings to complete his legal studies.

The young lawyer then decided to hazard his fortunes in the "Northwest" of that time, and accordingly entered the law office of Senator Augustus S. Porter, of Detroit, in September, 1836. In the next year he was admitted to the Michigan bar and soon became a partner of George F. Porter. The firm were the legal advisers of the Bank of Michigan, at that time the only banking institution in the vicinity, and after its collapse Messrs. Joy and Porter were very busy in straightening out the affairs of the corporation. They were so successful in this work that a large and lucrative practice was soon built up, and when in 1847, the State was without funds and in a most embarrassed condition, Mr. Joy's standing was such that he was enabled to save its reputation.

Michigan was at that time suffering from a plethora of public works.

* Memoir prepared from information furnished by George S. Morison, Past-President Am. Soc. C. E., and Allen Bourn, Esq.

into the history of which it is unnecessary to enter here. Among these public works was the Michigan Central Railroad. This property was one which Mr. Joy considered to have considerable value, so he worked with John W. Brooks, a well-known railroad engineer, to induce eastern parties to buy it. The undertaking was successful, the credit of the State was made good, and the young lawyer was launched on his very successful railway career, which, strange to say, in view of the commanding position he won, was never particularly attractive to him, as his preference was for a general practice. The importance of this sale can be shown by quoting Mr. Joy's description of the conditions prevailing in 1846:

"A wave of wild speculation had swept over the country a few years before, which had resulted in almost universal bankruptcy. All the banks in the State had failed. The State itself was utterly bankrupt. It had issued State scrip to pay for work on its railroads until it had become practically worthless. The railroads were of strap rails laid on wooden stringers and well nigh worn out, and its construction could not be continued, nor could the State reconstruct it with heavier rails. The State was prostrate so far as its credit was concerned. There was no railroad through Canada. There was no railroad west of Kalamazoo."

The old portion of the Michigan Central was rebuilt by its new owners, and the railroad was extended to Chicago, being opened in May, 1852. Through the Great Western Railway from Windsor, opposite Detroit, to Suspension Bridge, it formed, with the New York Central Railroad, one of the early trunk lines. The same capitalists who built the Michigan Central Railroad subsequently gathered and built the various lines which formed the Chicago, Burlington and Quincy Railroad (in Illinois), and Mr. Joy was a prime mover in its original construction. On the retirement of Mr. J. W. Brooks in 1865, Mr. Joy became President of the Michigan Central Railroad, and the active head of all the western interests controlled by the same set of capitalists. He was also President of the Chicago, Burlington and Quincy Railroad from 1865 to 1871.

In 1866 the revival of railroad construction after the war began. The Chicago, Burlington and Quincy Railroad terminated at the Mississippi River, but it had a connecting line which extended from Burlington about half way across the State of Iowa, while the Hannibal and St. Joseph Railroad, a Quincy connection, owned in the same interests, formed another western route. This gave an opportunity for extensions on two lines, westward to Nebraska and southwestward to Kansas. Mr. Joy favored the southwesterly extensions. In pursuance of this idea he arranged to construct a branch of the Hannibal and St. Joseph Railroad which should cross the Missouri River at Leavenworth, Kan., and connect with extensions to be built subse-

quently. The arrangements to construct this line were virtually completed when, owing to a disagreement with the Leavenworth authorities, Mr. Joy changed the terminus from Leavenworth to Kansas City. The first bridge across the Missouri was built here under his orders, the result being the development of the most important city on the Missouri at this point. Mr. Joy then took up the Missouri River, Ft. Scott and Gulf Railroad, then locally called the Border Tier Railroad, a line leading south from Kansas City through the eastern tier of counties in Kansas to the Indian Territory, across which it was to be extended to a connection with the railroad system of Texas, and he also built a more westerly line leading south from Lawrence and subsequently connected with Kansas City. Mr. Joy was at this time called the railroad king of the southwest. The Missouri River, Ft. Scott and Gulf Railroad was completed to the southern line of the State in 1870, but a disappointment awaited him here; he failed to secure the right to build across the territory, which was given to the Missouri, Kansas and Texas Railway, and his Kansas system was never developed on the original lines.

During the same period Mr. Joy constructed several important railroads in Michigan, the most prominent being the Jackson, Lansing and Saginaw Railroad, which became a part of the Michigan Central Railroad, and the Chicago and Michigan Lake Shore Railroad (now the Chicago and West Michigan) which follows near the east shore of that lake.

Mr. Joy's connection with the Chicago, Burlington and Quincy Railroad was finally terminated in 1875, when he ceased to be a director. A change took place in the ownership of the Michigan Central Railroad, and Mr. Joy's presidency ended in 1876; this closed his active life as a railroad manager. Mr. Joy, however, retained a strong interest in everything affecting his city, and was earnest in securing the extension of the Wabash system to Detroit. He was a director of this system for several years and its President from 1885 to 1886. His last active railroad work was in connection with the New Fort Street Passenger Station in Detroit and the construction of the railroad from Chicago to Montpelier, O., which gave the Wabash a line under its own ownership between Detroit and Chicago.

Mr. Joy was universally recognized as one of the ablest railroad lawyers of his time. He was, however, an advocate rather than a judge. As a railroad manager he was one of the most energetic promoters the country has ever had; as a conservative manager of an established property, he was less successful. He was a man of remarkably strong personality, and though in his later years his full beard was perfectly white, he retained the apparent energy and activity of his earlier life.

Mr. Joy died on September 24th, 1896, leaving a daughter and three sons. He was elected a Fellow of the American Society of Civil Engineers on November 6th, 1872.

MARK TUCKER SEYMOUR, F. Am. Soc. C. E.*

Died May 30th, 1885.

Mark Tucker Seymour was born at Stillwater, Saratoga County, N. Y., on March 23d, 1820. He was a descendant of a family which was among the first to settle in that part of the country, and took a prominent part in public affairs at the time of the Revolution.

Mr. Seymour's early life was spent on a farm, his spare moments being given to study, particularly of matters relating to mechanics. His early engineering training was acquired as an apprentice to his eldest brother, who was a surveyor. He spent some time mapping the country in which he lived, and locating and constructing a number of railway lines in the western part of New York State. He afterwards made a specialty of bridge building, his first important contract being for the construction of all bridges on the Erie Railway, among them the original Portage Viaduct. He next undertook extensive contracts in Virginia, which were abandoned at the outbreak of the civil war. In 1869 he had a contract for building bridges on the Union Pacific Railway, including those at Dale Creek and Devil's Gate. He took similar contracts from the Chicago and South Western Road in 1870, the Canadian Southern in 1871, and the Massachusetts Central in 1881. An undertaking of a different character which he also contracted for was the Riverside Drive in New York City. The last ten years of his life were spent in New York, to which city he moved from Chicago where he lived for four years.

Mr. Seymour was elected a Fellow of the American Society of Civil Engineers, July 21st, 1870.

* Memoir prepared from information furnished by George S. Morison, Past-President Am. Soc. C. E., and from papers on file at the House of the Society.

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OF THE

American Society of Civil Engineers.

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